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# SUBSTRATE ASSOCIATED RECRUITMENT OF JUVENILE *SEBASTES* IN ARTIFICIAL REEF AND NATURAL HABITATS IN PUGET SOUND AND THE SAN JUAN ARCHIPELAGO, WASHINGTON

by

Raymond Milo Buckley

A dissertation submitted in partial fulfillment of
the requirements for the degree of

Doctor of Philosophy

University of Washington

1997

Approved by Bruce S. Miller
Chairperson of Supervisory Committee

Program Authorized
to Offer Degree School of Fisheries

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## Abstract

# SUBSTRATE ASSOCIATED RECRUITMENT OF JUVENILE *SEBASTES* IN ARTIFICIAL REEF AND NATURAL HABITATS IN PUGET SOUND AND THE SAN JUAN ARCHIPELAGO, WASHINGTON

by Raymond Milo Buckley

Chairperson of the Supervisory Committee
Professor Bruce S. Miller
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Habitat pathways and temporal and spatial parameters of substrate associated recruitment have never been reported for juvenile quillback rockfish (*S. maliger*) in any ecosystem, and have never been described for juvenile copper (*S. caurinus*) and splitnose (*S. diploproa*) rockfish in Washington waters. In 1991-1994, juvenile quillback rockfish recruited only during July-August each cohort-year, correcting biannual recruitment errors in the literature for Puget Sound; first recruitment was apparently to offshore benthic habitats, with subsequent migrations to nearshore benthic macrophytes. Copper rockfish recruited during July-September each cohort-year; first recruitment was to surface and shallow water macrophytes attached to benthic substrates, with subsequent migrations to benthic macrophytes. During November-January, juvenile quillback and copper rockfish in natural macrophyte habitats migrated offshore associated with benthic drift macrophytes; juveniles in artificial and natural reef habitats migrated to deeper water associated with crevices in the substrates. Juvenile splitnose rockfish recruited during June-August each cohort-year; first recruitment was to surface drift macrophyte and seagrass habitats, which were vacated by December. Apparently co-occurring pelagic juvenile copper and splitnose rockfish selectively recruited to attached and detached vegetation habitats, respectively

Development of internal micro-tagging procedures for juvenile *Sebastes* enabled the first estimation of instantaneous natural loss rate (mortality and emigration) for this genus, without non-immigration assumptions. The estimate of $Z_{258d}$ = 0.0106 for juvenile quillback rockfish on an artificial reef recruitment habitat, was lower than for a coastal pelagic species, the only other estimate for juvenile *Sebastes*. Nearshore artificial reef substrate manipulations functioned as juvenile rockfish recruitment habitats, providing preferred nursery and refuge habitats and enhancing local recruitment. Efficacies of artificial reef recruitment habitats located adjacent to, and isolated from, established artificial reefs, were affected by variability in levels of juvenile rockfish recruitment, biogenic habitat parameters, and ecological maturity of the substrates. Micro-tagged juvenile rockfishes remained on artificial reef recruitment habitats during the cohort-year, contrasting emigrations from natural macrophyte habitats. Increased densities of juvenile rockfish on artificial reef recruitment habitats late in the cohort-year indicated emigrations from natural habitats. Juvenile rockfish had average daily growth rates of 0.11-0.13 mm total length in both natural and artificial reef recruitment habitats.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBREVIATIONS

ARH - adjacent recruitment habitat

BCAR - Boeing Creek Artificial Reef

CWT - coded-wire tag

c-y d - cohort-year day

EKM - Edmonds kelp and macrophyte habitat

GIAR - Gedney Island Artificial Reef

GIKM - Gedney Island kelp and macrophyte habitat

IRH - isolated recruitment habitat

MKM - Meadowdale kelp and macrophyte habitat

MS222 - tricane fish anesthetic

PS - Puget Sound

SJA - San Juan Archipelago

SJF - Strait of Juan de Fuca

VIF - Visible Implant Fluorescent

YOY - young-of-the-year

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# DEDICATION

For Marta Gómez-Buckley, my marine biologist wife, who has guided me to a life full of the joys of working and playing together.

In memory of Todd Michael Buckley (1968-1990), my son, who was taken just as he was learning the excitement of the underwater world.

# INTRODUCTION

## ECOLOGICAL IMPORTANCE OF *SEBASTES*

Rockfishes (Scorpaenidae: *Sebastes*) are a remarkably speciose group of marine fish found in the Pacific and Atlantic Oceans, with 105 species (Wourms 1991) to 106 species (Barsukov 1981) in the genus. This wide distribution includes about 35 species in the northwestern Pacific Ocean (Masuda et al. 1984), approximately 63 species (Robins et al. 1980) to 65 species (Chen 1971) in the northeastern Pacific Ocean, four species in the north Atlantic Ocean (Kendall 1991), and at least one species (Chen 1971), and possibly four to five species (F. Jara S., Universidad Austral de Chile, personal communication), found in the southern hemisphere. Along the Pacific Coast of North America, regional distributions range from 62 species off California (Hallacher and Roberts 1985), to at least 35 species off British Columbia (Hart 1980). There have been 26 species of rockfish recorded from Puget Sound, Washington (Miller and Borton 1980). Throughout their range, rockfishes are found in virtually all marine habitats, from the intertidal zone to depths greater than 1000 meters, over most types of bottom habitat, and throughout much of the water column (Love et al. 1990). Rockfishes associated with benthic habitats are typically found on high-relief rocky substrates, but substrate affinity in *Sebastes* can range from cryptic to semipelagic (Haldorson and Love 1991).

Reproductive biology in *Sebastes* is a primitive (*sensu* Wourms 1991) form of viviparity, with the embryos developing within the egg envelopes for most of the gestation period and then hatching several days prior to parturition (larval extrusion). The apparent flexibility in the time between mating and parturition seems to enable adaptive responses by adults to food availability (Larson 1991) and environmental factors (Wyllie Echeverria 1987) to optimize reproductive success. Energy is supplied to the developing embryos during gestation (matrotrophic viviparity) in at least four species of *Sebastes* (Boehlert and Yoklavich 1984, Boehlert et al. 1986, Dygert and Gunderson 1991, Takemura et al. 1995) through absorption of maternal substances by the embryonic epidermis and hindgut epithelium (Shimizu et al. 1991). The maternal contribution of energy to developing embryos can range from 11.5% to 92.1% between species (Dygert and Gunderson 1991), indicating considerable differences in evolutionary development of reproductive processes within the genus. This effective mode of reproduction has contributed to the success of *Sebastes* through high fecundity and enhanced survival of the embryos and larvae; extra-embryonic sources of nutrition during gestation may allow larvae to retain yolk reserves for use after parturition and enhance survival during the first phases of feeding (Wourms 1991). The reproductive partitioning resulting from viviparity in *Sebastes* has been suggested as a possible factor contributing to the genus becoming so speciose (Kendall and Lenarz 1987) by allowing distinct, but similar, species to co-occur.

The timing and duration of parturition in *Sebastes* shows considerable variability between species, and within species, between regions and years (Wyllie Echeverria 1987). Parturition in *Sebastes* is inferred primarily from studies of changes in gonad developmental stages in harvested adults (e.g., Haldorson and Love 1991, Nichol and Pikitch 1994), and from collection and rearing of pregnant fish (e.g., Kusakari 1991). Parturition has been studied in 46 northeastern Pacific species and 6 northwestern Pacific species (Haldorson and Love 1991), and very few throughout their ranges. For some species, and in some regions, the only information on parturition comes from early studies (e.g., DeLacy et al. 1964) which may not extrapolate accurately to current environmental conditions, sources and rates of mortality, and population sizes, all of which can affect life history parameters and reproductive strategies in *Sebastes* (Wyllie Echeverria 1987, Norton 1987). More direct studies of parturition through collecting larvae and spawning adults are hampered by the inability to identify the larvae and pelagic juveniles of most species (Moser et al. 1977, Moser and Boehlert 1991), and by the general lack of information on depths and locations of parturition and pelagic nursery habitats.

Relatively little is known about the ecology of larval and pelagic juvenile *Sebastes*, except that many species are widely distributed, often considerable distances from the adult benthic habitats, and over markedly different depth regimes than those occupied by the adults (Moser and Boehlert 1991). Pelagic juveniles of some species have variable midwater residence times and habitats, that may be in response to oceanographic conditions and location of appropriate benthic habitats (Boehlert 1977, Moser and Boehlert 1991, Larson et al. 1994). The impact of this dispersal on replenishment of local and regional rockfish populations is not well understood (Larson 1980, Carlson and Straty 1981, Love et al. 1991). All of the inadequately defined parameters for pelagic phases of *Sebastes* make it difficult to understand and anticipate the inter-annual temporal and spatial variability common in early post-pelagic phases.

Wide distribution patterns and large numbers of species make *Sebastes* important components of most ecosystems where they occur. Rockfish larvae are one of the most abundant kinds of fish larvae in the north Atlantic and north Pacific Oceans (Ahlstrom 1961, Bainbridge and Cooper 1971), and their abundance has also been noted in plankton surveys conducted in the non-coastal marine waters of Washington (Waldron 1972, Miller et al. 1977). Both larval and juvenile rockfishes are pelagic for varying periods, depending upon the species and prevailing oceanographic conditions. This may enhance transport and settlement to appropriate benthic habitats (Larson et al. 1994), but may also result in potentially extended periods of vulnerability to pelagic predation (Carr 1991).

Larvae and juveniles of many species of *Sebastes* have significant trophic value in pelagic ecosystems as prey for a variety of fishes, such as chinook salmon (*Oncorhynchus tschawytscha*; Ralston 1990), Pacific hake (*Merluccius productus*; Hobson and Howard 1989), and tunas (Scombridae; Pinkas et al. 1971), and even in inter-larval predation by Atlantic mackerel (*Scomber scombrus*; Fortier and Villeneuve 1996). Juveniles, and adults of smaller-sized species, also have substantial trophic value in benthic ecosystems for numerous piscivorous fishes, including lingcod (*Ophiodon elongatus*; Hallacher and Roberts 1985), Arctic cod (*Gadus morhua*; Casas and Paz 1994), Greenland halibut (*Reinhardtius hippoglossoides*; Pedersen and Riget 1992), and undoubtedly sculpins (Cottidae; author, personal observation). Juveniles of some rockfishes are also common in the diets of a variety of other marine picivors, ranging from the thorny skate (*Raja radiata*; Berestovskiy 1989), to the short-finned squid (*Illex iliecebrosus*; Dawe 1992), to the rhinoceros auklet (*Cerorhinca monocerata*; Vermeer and Westrheim 1984). Although predation on juvenile rockfishes by older congeners is often mentioned (e.g., Love et al. 1991), food habit studies indicate that intra-generic predation is infrequent (Patten 1973, Prince and Gotshall 1976, Moulton 1977, Hueckel and Stayton 1982, Brodeur and Pearcy 1984, Hueckel and Buckley 1987, Rosenthal et al. 1988, Murie 1995, 1991, NOAA/NMFS Northwest and Alaska Fisheries Center, unpublished), except on the small-sized Puget Sound rockfish, *S. emphaeus*, (Rosenthal et al. 1988), and on juveniles during mass settlement, density dependent situations during coastal upwelling conditions in California ecosystems (Love and Westphal 1981, Hallacher and Roberts 1985). Cannibalism has been recorded in diet studies of some species of *Sebastes* (Love and Westphal 1981, Magnusson and Palsson 1989), but it is apparently not common in the genus (see Cannibalism and Other Predation).

In many species of *Sebastes*, early post-pelagic juveniles feed heavily in the nearshore water column on zooplankton, removing large numbers of larvae destined for intertidal and subtidal habitats (e.g., barnacles; Gaines and Roughgarden 1987), and possibly influencing the distribution and relative abundance of species in these habitats (Love et al. 1991). Sub-adults and adults of many rockfishes are important top predators and competitors in nearshore benthic ecosystems (coastal California - Love and Westphal 1981, Hallacher and Roberts 1985; Gulf of Alaska - Rosenthal et al. 1988; Puget Sound - Buckley and Hueckel 1985, Hueckel and Buckley 1987), some species possibly having keystone roles (*sensu* Paine 1966) in structuring biodiversity and promoting energy transfer in these systems (Simenstad et al. 1977, Bohnsack 1981, Hallacher and Roberts 1985, Rosenthal et al. 1988, Ryder and Kerr 1990, Hixon 1991, Hixon and Beets 1993, Caley 1995).

The ecological importance of the complex of species forming *Sebastes* is not emphasized in most studies of the biology and ecology of this group of fishes; these studies instead highlight the importance of rockfishes in recreational and commercial fishery harvests, and the need for information related to the management of these fisheries (Laroche and Richardson 1980, Haldorson 1987, Love et al. 1990, Murie et al. 1994, Murie 1995, and others). Many rockfishes are important in fishery harvests throughout their ranges, and these harvests are often the subject of complex fishery management deliberations by natural resource agencies and regional fishery management councils (Pacific Fishery Management Council 1989). However, despite attempts at regulating fisheries to conserve resources, extensive and excessive harvesting of many stocks of *Sebastes* has resulted in extended periods of over-exploitation (Archibald et al. 1983), to the extent that once exploitable stocks of some species have decreased dramatically.

Harvests targeting some species of *Sebastes* also compete with intense predation removals of juveniles and sub-adults of these species by piscivorous fishes, that are also targets of fishery harvests (Tretyak et al. 1991, Casas and Paz 1996). The result of the "double harvests" of these *Sebastes* is a severe disruption of natural predator-prey relationships, which increases rates of cannibalism in the predators due to reductions in the abundance of preferred prey, and reduces the sizes of the younger age-groups of the prey (Casa et al. 1991, Ajiad et al. 1992, Dolgaya and Tretyak 1992). The management of these inter-related fisheries requires stock assessments and catch predictions that include both predation-caused and fishing mortalities of the *Sebastes* that are prey species (Tretyak et al. 1991, Ajiad et al. 1992). This level of management requires significantly improved information on the ecological processes affecting the natural production of many *Sebastes* (Roberts 1997).

## SUBSTRATE ASSOCIATED RECRUITMENT

At the time of settlement from pelagic habitats, juveniles of many species of *Sebastes* become strongly associated with various substrates in the local habitat (Carr 1991, Danner et al. 1994); the type of substrate differs markedly among species (e.g., algae, rock, sand, mud; Love et al. 1991). This spatial transition of post-pelagic juveniles from one habitat to another, and the corresponding temporal and ontogenetic transitions from one phase of life to another, is the substrate associated recruitment period in juvenile rockfish ecology. These movements into new ecosystems and life history intervals result in changes in the physical and ecological parameters affecting juvenile rockfishes, which can dramatically alter a host of biotic and abiotic factors related to their survival. During and after the substrate associated recruitment period, the distribution and abundance of juvenile *Sebastes* reflect the availability of critical resources in the various habitats, sources of mortality, and movement among habitats. These factors, singly or in combination, are likely to be responsible for the habitat associations exhibited by the juvenile rockfishes (Love et al. 1991).

The highly dispersive nature of the pelagic larval and juvenile stages of most *Sebastes* results in the success of the juvenile substrate associated recruitment phase having a strong influence on the distribution and abundance of later life stages in local habitats. In some species year-class strength may be determined by the late pelagic juvenile stage (Ralston and Howard 1995). The potentially protracted duration of the pelagic phases essentially decouples local production of larval *Sebastes* from the supply of recruits to local populations, making recruitment of juveniles largely dependent upon larvae produced elsewhere (Sissenwine 1984, Carr 1994a). The initial distributions and abundance of pelagic juveniles are probably strongly influenced by stochastic variations in the availability (i.e., supply) of larval stages (Doherty and Williams 1988a, Moser and Boehlert 1991), particularly in situations where there is a dynamic coupling of oceanographic processes and the levels of recruit availability (Stephens et al. 1984, 1986, Ebeling and Hixon 1991, Milicich 1994); however, variability in the number of juvenile *Sebastes* successfully recruiting to appropriate substrates can be the ultimate determinant of local population sizes (Sissenwine 1984, Richards and Lindeman 1987, Bradford 1992).

Assessments of ecological parameters affecting recruitment and survival of juvenile marine fishes during the early substrate association phase, have received considerable empirical and theoretical consideration in studies of tropical reef ecosystems (Sale et al. 1980, Shulman 1984, 1985, Behrents 1987, Doherty 1991, Jones 1991, Sale 1991a,b). These studies have identified many parameters that appear common to both tropical and temperate nearshore reef systems, particularly that complex spatial and temporal variability in the supply of recruits strongly influences fish community structure, and that recruitment patterns are modified by a wide range of interacting post-recruitment processes. Tropical reefs are defined as open non-equilibrial systems, in that gains (recruitment) from external sources, and internal losses (mortality), have more control over fish abundance and community structure in the local environment than local carrying capacity (Doherty 1991). These studies also note that (at least) in tropical systems the spatial, temporal, and theoretical scales at which observations and experiments are conducted can dramatically influence results.

The current status of reef fish ecological studies shows that there are differences between tropical and temperate reef fish communities, especially in variability of habitat structure, and that there is no "single factor" regulating all reef fish community structure (Ebeling and Hixon 1991). There are few comparative studies of these two ecosystems (Jones 1988a, Ebeling and Hixon 1991, Love et al. 1991), but it is fairly certain that the results of recruitment studies from relatively temporally stable tropical, coral reef dominated, habitats have limited applications in the structurally dynamic, macrophyte dominated, habitats of temperate ecosystems, which are common for many rockfishes (Holbrook et al. 1990a, Carr 1991).

Most studies of recruitment and survival of juvenile temperate reef fishes have been concerned with the effects of recruitment habitat complexity, availability, and selection on the recruitment and survival of juveniles (Steiner et al. 1982, Stephens et al. 1984, Behrents 1987, Choat and Ayling 1987, Holbrook et al. 1990b, Carr 1991, Connell and Jones 1991, Levin 1991, Anderson 1994), and the primary empirical work has investigated manipulations of algal habitats (Jones 1984, Carr 1989, 1994a,b). Appropriate habitat for juvenile marine fishes, in particular shelter-habitat, appears to be very important for successful juvenile recruitment and survival, however, habitat refuge value may interact with habitat foraging value (Rangeley and Kramer 1995), or be of secondary importance to food supply (Levin 1994) for some temperate reef fishes.

Potentially limiting resources for substrate associated juvenile *Sebastes* include food and shelter, or territory (habitat) availability (Larson 1980). There is no evidence that starvation (Singer 1985) is a major factor in the natural mortality of most substrate associated juveniles, however, shelter is important, as predation by piscivorous fishes (Love and Westphal 1981, Hallacher and Roberts 1985) and birds (Ainley et al. 1981, Vermeer and Westrheim 1984) can be substantial.

Assessments of habitat selection by juvenile rockfishes and other temperate reef fishes, have been concerned primarily with predation rates and foraging success (e.g., Gilliam and Fraser 1987, Nelson and Bonsdorff 1990); however, habitat selection related to habitat abundance and variability is receiving increasing attention (Carr 1991, 1994a).

The transition from nektonic juveniles, to benthic substrate associated juveniles, often involves one or more intermediate non-benthic and pelagic habitats for several rockfishes. Many *Sebastes* in the northeastern and northwestern Pacific Ocean recruit from the nekton to drift habitats of detached macrophytes and seagrasses (Mitchell and Hunter 1970, Boehlert 1977, Fedoryako 1989, Safran and Omori 1990, Buckley et al. 1995), and occasionally other flotsam (Hitz 1961), apparently as the first substrate association. Juveniles of at least one species migrate from the surface drift habitats, back to pelagic habitats in mid-water, possibly for periods of up to several months, prior to association with benthic habitats (Boehlert 1977). Substrate associated recruitment of several Pacific Ocean species of *Sebastes* is positively related to the presence of macrophytes, and there are frequently ontogenetic shifts among attached macrophyte habitats after the first substrate association (Hobson and Chess 1976, Carr 1983, Haldorson and Richards 1987, Carr 1991, Love et al. 1991).

Juvenile *Sebastes* generally recruit to benthic habitats shallower than the depths of conspecific adults (Boehlert 1977), or at least to the shallowest depths of the adult range (Love et al. 1991), with juveniles of deeper dwelling species settling at deeper depths. This process of settlement to demersal populations is a major event in recruitment for all marine fishes (Sale 1990). Despite the importance of this juvenile period, studies of most temperate reef fishes have been directed mainly by theoretical and historical approaches, and have concentrated on the larval, sub-adult, and adult phases (Love et al. 1991). Difficulties in sampling in the rugose habitats of many juvenile rockfishes, have also contributed to neglecting assessments of the processes occurring during the important substrate associated juvenile recruitment period; these processes may strongly influence numbers of sub-adult and adult rockfishes occurring in various habitats. In the most current review of substrate associated juvenile rockfishes, Love et al. (1991) note that the importance of refuge habitat availability to juvenile recruitment and post recruitment survival, has not been widely studied.

## RESEARCH ON JUVENILE *SEBASTES* IN WASHINGTON WATERS

There is a limited amount of research on *Sebastes* found in northeastern Pacific waters that includes information on juvenile life stages. Some information on juvenile rockfishes can be found in recent annotated bibliographies (Leet and Reilly 1988, Norris 1991), but the primary sources are reviews covering the larval and juvenile stages (Kendall and Lenarz 1987, Love et al. 1991, Moser and Boehlert 1991). However, most of the information that is available covers only portions of the ranges of the species, and it is often incomplete for many species. Recent contributions have been made to the ecology of some juvenile rockfishes found along the central California coast by studies on recruitment of juveniles in macrophyte habitats (Carr 1991, Danner et al. 1994), and by studies to predict year-class strength of some *Sebastes* from assessments of juveniles in nearshore habitats, and from the numbers of juveniles in the diets of chinook salmon caught in offshore waters (Lenarz and Moreland 1985, Hobson et al. 1986, Larson 1987, Whipple 1988, Hobson 1989, Ralston 1990).

Some inferences can be made about the substrate associated recruitment of juvenile *Sebastes* in Washington waters using the information from California, and results from Alaska studies (Larson 1980, Carlson and Straty 1981, Hallacher and Roberts 1985, Wilson and Krenn 1986, Gaines and Roughgarden 1987, Holbrook et al. 1990a, Carr 1991). However, these studies relate to recruitment of usually different species of juvenile rockfishes which are influenced by significantly different environmental parameters, habitat configurations, and population dynamics than are present in Washington, especially in the non-oceanic marine waters. For example, the semi-enclosed, non-oceanic marine waters of the Strait of Juan de Fuca, the San Juan Archipelago, and Puget Sound have far fewer species of *Sebastes* (e.g., 62 species off California - Hallacher and Roberts 1985, 26 species in Puget Sound - Miller and Borton 1980) recruiting to possibly less abundant nearshore habitats, compared with California and Alaska, where the proximity of expansive habitats to coastal waters provides extensive nearshore macrophyte dominated communities, and recruitment from "open systems" (*sensu* Doherty 1991) and species rich populations. Therefore, while information from California and Alaska is helpful, extrapolations to *Sebastes* found in Washington's non-oceanic and coastal waters can be tenuous.

Research on juvenile *Sebastes* in the non-oceanic waters of Washington and adjacent regions has increased in recent years in response to biological concerns for the status of the once plentiful rockfish resources. A major source of uncertainty in managing rockfishes in this region is the lack of knowledge about factors affecting recruitment (Gowan 1983). Earlier studies in localized areas contained some biological and ecological information on juvenile rockfishes (Patten 1973, Gascon and Miller 1981), and there is limited data on the occurrence of demersal juvenile rockfishes in some nearshore habitats resulting from general ecological studies (Moulton 1977), studies designed around other objectives (e.g., Donnelly et al. 1984), or anecdotal accounts. Later, more regional, studies examined habitat use by juveniles and older life stages of *Sebastes*, and noted that there is little information on the locations of the nursery habitats for most north Pacific Ocean species (Carlson and Straty 1981), and that habitat affinities and requirements for juvenile and young-of-the-year rockfishes are unknown in the Puget Sound region of Washington (Mathews 1988, 1990). There are several recent studies concerned with the biology, ecology, and habitat use of the substrate associated juvenile life phase of *Sebastes* (Haldorson and Richards 1987, West et al. 1994, Buckley et al. 1995, Doty et al. 1995, Shaffer et al. 1995, West et al. 1995), some of which identify nursery habitats and trophic interactions that are apparently critical to survival of the juveniles. Unfortunately, some studies of *Sebastes* in this region, that could have provided valuable information on juvenile rockfishes, exclude this life stage because of the difficulties in obtaining accurate counts and samples of these small fishes in rugose, macrophyte dominated, habitats (Richards 1987).

Assessment of this information reveals three important points concerning the ecology of juvenile *Sebastes* in the non-oceanic waters of Washington: (1) There is limited information on the environmental parameters and processes affecting substrate associated recruitment and post-recruitment survival; (2) There is incomplete understanding of the recruitment pathways and habitats used to transition from the first substrate association to sub-adult and adult habitats, and which of these intermediate habitats may be critical or obligate to survival; (3) There is little quantitative or qualitative information on the effects of manipulations of recruitment habitat on substrate associated recruitment and post-recruitment survival.

## OVERALL RESEARCH OBJECTIVES

There are two overall objectives for the Dissertation research presented here, which are in response to the need for ecological information on the processes affecting local natural production of *Sebastes* resources in the non-oceanic waters of Washington:

I. To clarify the substrate associated recruitment ecology of juvenile copper rockfish (*S. caurinus*), quillback rockfish (*S. maliger*), and splitnose rockfish (*S. diploproa*) in macrophyte habitats, and in natural and artificial rocky-reef habitats, in northcentral Puget Sound and the San Juan Archipelago.

II. To determine if manipulating artificial rocky-reef substrates in northcentral Puget Sound, to simulate natural recruitment habitats used by juvenile copper rockfish and quillback rockfish during substrate associated recruitment, will enhance local natural recruitment and survival of these species.

It is important in ecological studies to avoid problems created by inadequately defined recruitment terminology (Richards and Lindeman 1987, Booth and Brosnan 1995). The term recruitment denotes permanent temporal and/or spatial transition of an organism from one phase of life to another. The period encompassed by recruitment often varies in relation to the objectives of the research being conducted, and, unfortunately, many of the definitions may be arbitrary with respect to the life cycle of the organism being studied (Booth and

Brosnan 1995). These problems can be avoided by clarifying the terminology and criteria for distinguishing the life history stages of the organism under study (Richards and Lindeman 1987). In current reef fish ecological research, the operational definitions of recruitment are usually either, the total number of fish surviving after settlement to the end of a specific period thereafter (Booth and Brosnan 1995, Forrester 1995), or the input of juvenile fish to the observable reef-based population (Jones 1991). For juveniles of species of *Sebastes* that become strongly associated with various substrates in the local habitat (Carr 1991, Love et al. 1991, Danner et al. 1994), the recruitment period begins with the settlement process, when the juveniles cease to be pelagic and become associated with a substrate for shelter, feeding, or orientation, and continues with subsequent ontogenetic movements over a period of time.

The transition of juvenile *Sebastes* from one habitat to another, and from one phase of life to another, is the substrate associated recruitment period in the ecology of copper rockfish, quillback rockfish, and splitnose rockfish that is of interest in this Dissertation research. This recruitment period is defined as coming after the pelagic juvenile phase (the prejuvenile phase of Boehlert 1977), and beginning with transition of juveniles to the first substrate associated phase. This recruitment period encompasses juvenile settlement to a substrate, and subsequent transitions of the juveniles to other substrates or habitats during approximately the first year of habitat associations. This is an ecologically realistic definition for the substrate associated recruitment period for juvenile *Sebastes*, because it includes the early post-settlement phase which is theorized to be the period of greatest mortality for juvenile reef fishes (Richards and Lindeman 1987, Sale and Ferrell 1988, Booth and Brosnan 1995), and the juveniles of many species of *Sebastes* are known to have ontogenetic movements during the early juvenile phase (Larson 1980, Haldorson and Richards 1987, Carr 1991, Love et al. 1991) which could affect survival.

Under the overall objectives of this research, advances will be made in the following areas important to preservation, management, and enhancement of *Sebastes* resources in these nearshore waters: (1) Determination of recruitment habitat pathways of the juveniles, and other ecological parameters important during the substrate associated recruitment of the juveniles, that contribute to successful natural production; (2) Contrasts of substrate associated recruitment of juveniles on natural and artificial reef habitats in Puget Sound; and (3) Estimation of the potential for enhancing natural recruitment of juveniles in local nearshore habitats in Puget Sound by using artificial reefs to increase the amount of recruitment habitat.

# CHAPTER 1: DEVELOPMENT OF INTERNAL MICRO-TAGGING TECHNIQUES TO MARK JUVENILE *SEBASTES*.

## INTRODUCTION

Distinguishing fish by a marking system, for either individual or batch recognition over time, is one of the basic tools used in biological and ecological studies to trace the fate of the fish under study. The marking or identification systems used by researchers in these fields are either intrinsic (related to the real nature of the fish) or extrinsic (dependent on external circumstances). The validity of either system relies on the assumption that identified fish are representative of their species, and thus provide unbiased data, within the context of the study (see Neilsen 1992).

Easily recognizable variations in natural marks, or other intrinsic characteristics, that can be used to identify individuals, or groups of juvenile or small-sized reef fishes (hereafter inclusively termed juvenile reef fishes), are severely limited and often of little value in studies conducted at large ecological scales. The extrinsic identification systems most commonly used in ecological studies of fishes, involve either using tags (attaching or injecting foreign materials), or altering, mutilating, or coloring specific body parts, to mark individuals or groups (Parker et al. 1990). Fish tags are seldom used to mark juvenile reef fishes, primarily because researchers consider only commonly used external tags (tags that have an internal anchor segment that passes through the integument to an external indicator segment) which are relatively large, and therefore physically incompatible with the small size of the fish.

The advantages, in most applications, of internal fish tags (those completely enclosed within the tissue of the fish) over external fish tags, have been recently reviewed by Buckley and Blankenship (1990) and Bergman et al. (1992). Internal tags are relatively benign if (1) the tag size is small relative to fish size, minimizing biological disruptions during implanting and within the tissues, (2) the tag locations are anatomically acceptable relative to biological functions of the fish, and (3) the tag materials are bio-compatible. Extremely small-sized (i.e., micro) internal tags increase potential applications in small fishes (fishes as small as 0.25 g - Thrower and Smoker 1984) in a variety of anatomical locations.

The binary-coded wire tag (CWT - Bergman et al. 1968) and Visible Implant Fluorescent (VIF) filament tag (Northwest Marine Technology Inc., unpublished, Buckley et al. 1994, Beukers et al. 1995) are bio-compatible internal micro-tags that are injected into various tissues to mark fish. The CWT micro-tag system uses a binary code etched on the surface of magnetically detectable, stainless steel wire, and has been tested in over 24 genera of fishes (Buckley and Blankenship 1990). The VIF filament micro-tag system uses hard monofilament that fluoresces (red) when exposed to ultra-violet-A (UV-A) light, and has been tested in at least two species of tropical reef fishes (Beukers et al. 1995), four species of temperate reef fishes (Buckley et al. 1994), and two species of crustacea and one holothurian (Buckley and Gómez-Buckley 1992). The VIF tags are externally visible when exposed to UV-A light when implanted in transparent or translucent tissues. The CWT and VIF tag systems (1) allow individual or batch recognition, (2) can be rapidly applied under field conditions, usually using anesthetic, (3) have high rates of retention in most species, (4) do not invalidate biological normality assumptions, and (5) enable practical long-term recovery of information.

## OBJECTIVES

The CWT and VIF tag systems were first tested to mark juvenile temperate reef fishes by Buckley et al. (1994). In this study, Buckley et al. applied both types of tags to juvenile *Sebastes* as part of the Dissertation research presented here. The overall objective for testing the CWT and VIF tag in juvenile *Sebastes* was to determine if these internal micro-tags could be used to identify specific groups of recruits early in the substrate associated recruitment phase. If either of these tagging systems could be applied to these small-sized fishes, it would be possible to track migrations and movements, and to remove immigration factors from survival estimates. The objectives of the aquarium tests of these micro-tags in juvenile *Sebastes* were (1) to develop tag application procedures for use in the field, (2) to determine the direct effects of the tags and tag application procedures on survival and growth, (3) to determine the long term tag retention rates in selected anatomical locations, and (4) to verify that the VIF tags implanted in juveniles could be fluoresced underwater with UV-A lights, from distances that would be encountered on visual transects in the field (at least 0.5 m).

## METHODS

All survival, growth, and tag retention tests were conducted on four groups of juvenile *Sebastes* (Table 1.1) captured by SCUBA divers using hand nets, between August 1990 and September 1991, and transferred to research tanks with flow-through sea water systems at public aquariums in Seattle and Tacoma, Washington. Juvenile copper rockfish (*S. caurinus*), quillback rockfish (*S.*

Table 1.1. Number and size of juvenile rockfishes used in micro-tag retention experiments[1].

| Group | Spp.[2] | N (0 d)[3] | Total Length (mm) |  | Day[5] | N | Total Length (mm) |  | Survival |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Range | Avg ± SD[4] |  |  | Range | Avg ± SD[4] | % |
| Rf 1 | PS | 28 | 62-90 | 81.0 ± 5.8 | 330 | 26 | 94-121 | 106.3 ± 7.5 | 92.9 |
| Rf 2 | Cr | ? |  |  |  |  |  |  |  |
|  | Qb | ? |  |  |  |  |  |  |  |
|  | Br | ? |  |  |  |  |  |  |  |
|  | Ps | 4 |  |  |  |  |  |  |  |
|  | Total | 62 | 47-94 | 63.9 ± 11.1 | 310 | 60 | 67-142 | 109.6 ± 19.2 | 96.8 |
| Rf 3 | Cr | ? |  |  |  | 21 |  |  |  |
|  | Qb | ? |  |  |  | 89 |  |  |  |
|  | Total | 120 | 30-62 | 40.7 ± 6.3 | 132 | 117 | 50-94 | 65.0 ± 7.9 | 97.5 |
| Rf 4 | PS | 77 | 36-49 | 41.6 ± 2.7 | 45 | 75 | 38-55 | 47.5 ± 3.6 | 97.4 |

1] From Buckley et al. 1995.

2] Br = brown rockfish, Cr = copper rockfish, PS = Puget Sound rockfish, Qb = quillback rockfish.

3] 0 d identification of some species inaccurate due to small sizes.

4] Average ± standard deviation.

5] Days post-tagging.

*maliger*), and brown rockfish (*S. auriculatus*) were captured in natural rocky-reef and macrophyte habitats in the northcentral Puget Sound region, and in the San Juan Archipelago. Juvenile Puget Sound rockfish (*S. emphaeus*) were captured on Boeing Creek artificial reef in Puget Sound. Research tank capacity varied from 1,000 to 2,000 l depending upon the volume needed to provide optimal growing conditions for the size and number of fish in each group. All fish were fed natural diets on a daily basis, at rates deemed to be optimal by professional aquarium staff experienced in rearing juvenile *Sebastes*. Natural rock substrate was placed in each tank to simulate natural habitat, and thereby provide conditions that would allow natural interactions and size segregations, and approximate natural growth.

Juvenile rockfishes in Groups Rf 2 and Rf 3 were mixed species of the same sizes due to initial visual identification difficulties with some species. Species determinations at small sizes are based mainly on meristic counts that are destructive. Later development of external characteristics, such as the presence of specific head spines and pigment patterns, combined with later meristic counts (Chen 1986, Matarese et al. 1989), enabled identification of species by the end of the study.

All fish were anesthetized with MS222 (tricaine) at a concentration of 0.05 g $l^{-1}$, immobilizing the fish to allow accurate placement of the tags using hand-held tag injectors. Tags and injector needles were placed in a tetracycline solution during tagging operations to maintain antiseptic conditions. All fish were tagged out-of-water, with the application of each tag requiring 10 to 15 seconds. Tagged fish recovered from the anesthetic (i.e., were swimming upright) in 30 to 120 seconds. Tagged fish were placed directly into the research tanks. CWT and

VIF tags were 1.0 mm long x 0.25 mm diameter. VIF tags were red fluorescent. Tagging operations were conducted under laboratory conditions.

The juvenile rockfishes of Groups Rf 1 and Rf 2 were used to test the retention of CWT in the cheek muscle (Figure 1.1.), due to their relatively larger sizes (Table 1.1). Cheek muscle is the tagging location that has shown considerable success in the anatomically similar striped bass (*Morone saxatilis* ; Klar and Parker 1986). The small cheek muscle mass in smaller-sized (i.e., younger) rockfishes, and the soft nature of the underlying opercle bones protecting the gills, does not present an optimal target location for implanting the CWT. The nape was tested as an alternate muscle implant location for CWT in the smaller rockfish of Group Rf 4.

CWT were injected into cheek muscle with the long axis of the tag oriented parallel to the muscle fibers, for maximum retention (Klar and Parker 1986). VIF tags were injected in translucent areas of the nape and mid-dorsal region, in the fibrous connective tissue layer of the dermis; this placed the tags under the scales, and above the underlying chromatophores, for maximum visibility. All tags were implanted at least one tag-length away from the needle insertion wound to allow a healing area behind the tag.

Tag retention tests were conducted under the criteria of (1) a minimum of 30 d to establish short-term retention, (2) 130 d to establish long-term retention, and (3), for VIF tags, at least 300 d for indications of continued external visibility with growth. Tag rejection, due to unacceptable tag location or tagging procedures, is usually established by 30 d (Blankenship 1990, Buckley and Blankenship 1990). Tag rejection rates that resulted in 20% or greater tag loss were considered

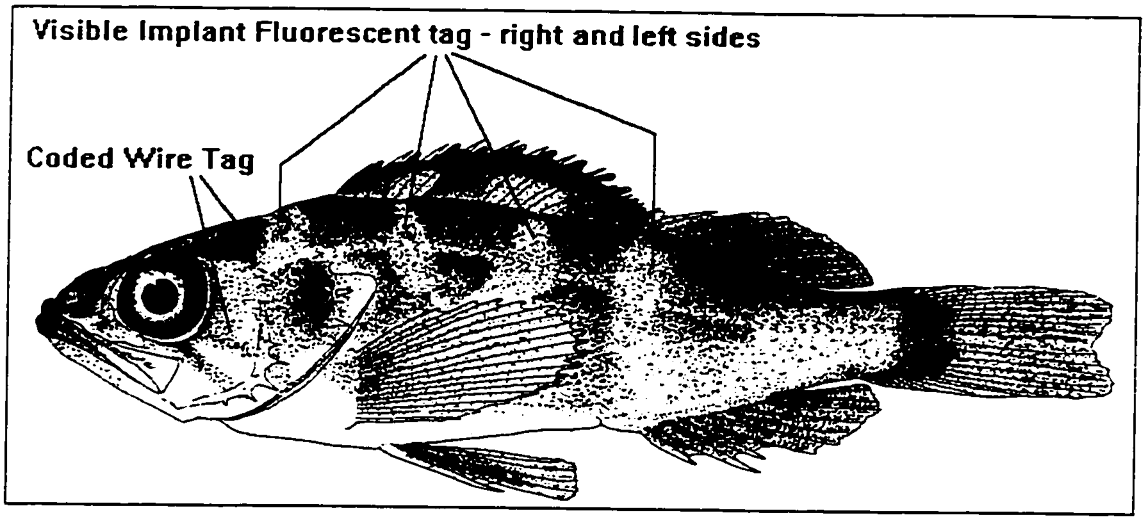

Figure 1.1. Anatomical locations of internal micro-tags (drawing from Matarese et al. 1989).

failures of the tag location. The presence of CWT was determined using a magnetic tag detector; VIF tags were detected visually using a 30 watt halogen underwater light, with UV-A transmitting filter over the lens. VIF tags were considered "lost or rejected" if they could not be detected visually; dissection recovery was not attempted for tags that may have been covered by tissue or chromatophores sufficient to block their detection, therefore, tag retention values are minimal estimates in the nape and mid-dorsal locations. Checks for tag retention in fish held in research tanks were made by examining anesthetized fish out-of-water.

## RESULTS

Evaluation of meristic characteristics during this study enabled valid identification of the juvenile copper rockfish, quillback rockfish, and brown rockfish (Chen 1986, Matarese et al. 1989, NOAA/NMFS Southwest Fisheries Science Center, unpublished), and confirmed morphological characteristics that had been observed with the growth of these rockfishes as aiding separation of these species at smaller sizes. The identification of juvenile Puget Sound rockfish from the Boeing Creek artificial reef was confirmed by (1) the early spring settlement of the juveniles to rocky substrates at 12 to 15 m depths (Moulton 1975), (2) fairly distinctive pigment patterns (Matarese et al. 1989), and (3) definitively high gill raker counts and other meristic characteristics (Chen 1986, Matarese et al. 1989).

The mean growth and survival of juvenile Puget Sound rockfish in Groups Rf 1 and Rf 4 were 25.3 mm total length (TL) and 92.9% in 330 d, and 5.9 mm TL and 97.4% in 45 d, respectively (Table 1.1). The last accurate length measurements for Group Rf 4 were at 45 d due to erosion of the caudal fin; this tag retention test was terminated at 69 d with 73 fish, due to a water system failure. The mean growth and survival for the mixed species of juvenile rockfish in Groups Rf 2 and Rf 3 were 46.0 mm TL and 96.8% in 310 d, and 24.3 mm TL and 97.5% in 132d, respectively (Table 1.1).

Retention of CWT in Groups Rf 1, Rf 2, and Rf 4 was 100% at 330 d, 310 d, and 69 d, respectively (Table 1.2). The 100% CWT retention at 69 d is a valuable test of the nape location, as it exceeded the 30 d minimum criteria for valid information. Retention of VIF tags implanted in the nape of the juvenile copper and quillback rockfish (Group Rf 3) was 92.7% at 132 d (Table 1.2). This tagging involved the first use of a new, semi-automatic, hand-held tag injector. The first 10 rockfish tagged in Group Rf 3 were used to develop the tagging technique, and placement of some of these 10 tags may have been suboptimal. Elimination of these fish from the group may have increased the tag retention percentage. Checks of tag retention relative to fish length in Group Rf 3 at 38 d and 68 d showed that tag retention was evenly distributed about the mean lengths (Table 1.3). Group Rf 3 included the smallest juvenile rockfishes tagged in this study (as small as 30 mm TL at 0 d).

The epidermis and dermis in the nape and mid-dorsal areas (Figure 1.1) of juvenile copper and quillback rockfish are relatively translucent and have minor pigmentation. Red VIF tags injected in these locations were usually visible under laboratory and natural ambient light, which assisted injection of the small tags in the proper location. However, the injected tags were virtually impossible to detect visually underwater under ambient white light, even at distances of 10-15

Table 1.2. Placement and retention of coded-wire tags (CWT) and Visible Implant Fluorescent (VIF) filament tags in groups of juvenile rockfishes.

| Tag | Tag Location[1] | Group[2] | Day[3] | N | Number Tagged | % Retention |
|---|---|---|---|---|---|---|
| CWT | Right cheek | Rf 1 | 330 | 26 | 26 | 100 |
| CWT | Right cheek | Rf 2 | 310 | 60 | 60 | 100 |
| VIF | Nape | Rf 3 | 132 | 110 | 102 | 92.7 |
| CWT | Nape | Rf 4 | 69 | 73 | 73 | 100 |

[1] See Figure 1.1.
[2] See Table 1.1.
[3] Days post-tagging.

Table 1.3. Retention of Visible Implant Fluorescent (VIF) filament tags in the nape of juvenile rockfishes in Rf 3[1] relative to mean lengths at 38 and 68 d post-tagging.

38 d

| Range[2] | N | Number Tagged | % Retention |
|---|---|---|---|
| 36-51 | 63 | 59 | 93.7 |
| 51.3 = Mean | | | |
| 52-75 | 47 | 44 | 93.6 |
| Total | 110 | 103 | 93.6 |

68 d

| Range[2] | N | Number Tagged | % Retention |
|---|---|---|---|
| 41-56 | 56 | 52 | 92.9 |
| 56.6 = Mean | | | |
| 57-85 | 54 | 50 | 92.6 |
| Total | 110 | 102 | 92.7 |

1] See Tables 1.1 and 1.2.
2] Total length in mm.

cm. VIF tags fluoresced brightly underwater when exposed to a UV-A light that was up to 1 m away from the tagged fish in the research tanks.

## DISCUSSION

### Intrinsic Identification Methods

The majority of ecological studies of juvenile reef fishes have either grouped morphologically similar species that could not be differentiated (Carr 1983, 1989, Mathews 1988, 1990, West et al. 1994, Doty et al. 1995, West et al. 1995), or they have relied on intrinsic identification systems to distinguish experimental fishes. Intrinsic identification has been used when (1) variations in the patterns of natural marks on the species allow individual identification (Connell and Jones 1991, Hunte and Côté 1989), (2) the natural sedentary or territorial behavior of the species makes it likely that individuals are found in the same vicinity from day to day (Sale and Ferrell 1988, Shapiro 1987), (3) distinct differences in size, morphology, or behavior, due to temporal separation of recruitment episodes, enables the identification of cohorts (Jones 1990, Robertson 1988, Victor 1986), and (4) adequate isolation of habitats enables identification of separate populations (Behrents 1987, Meekan 1988, Stimson 1990).

The use of intrinsic identification methods in studies requires accurate matching of species, behavior, ontogeny, and habitat configuration, with the study objectives. This places considerable limitations on the species, ecosystems, and spatial, temporal, and demographic parameters, that can be studied. In response to these limitations, most of the studies relating to equilibrial assemblages of coral reef fishes have concentrated on small, site-attached, herbivorous and planktivorous fishes (Doherty and Williams 1988a, Sale 1991a). Studies using intrinsic identification to trace fish often include significant assumptions of non-emigration and/or non-immigration (Behrents 1987, Eckert 1987, Jones 1988b, 1990), and sometimes the requirement of low rates of recruitment to reduce the numbers of similar-aged, co-habiting fish (Sale and Ferrell 1988).

Some recent studies of juvenile reef fishes have used extrinsic identification systems, such as heat brands and liquid latex injections, for external marks, and tetracycline immersions to mark otoliths, but these methods have significant biological limitations. Heat brands produce biological stress from mutilation, and the marks have limited duration (only 4 months in 1-year-old *Pomacentrus amboinensis*; Jones 1987a). Liquid latex injected under the skin produced visible colored marks (in *Dacyllus aruanus* >25 mm fork length; Forrester 1990), but the bio-compatibility of liquid latex was not established (Riley 1966). Tetracycline marks can only be recovered through sacrificing specimens, and marking requires extensive application periods (24 hour immersion for *D. aruanus*; Forrester 1990).

### Internal Micro-tags

The results of this study confirmed that extrinsic identification of juvenile *Sebastes* with the internal CWT and VIF tag is feasible, and that these systems have many potential applications in ecological studies. The ability to quickly distinguish live experimental fishes from all others in the ecosystem, removes many constraining assumptions. This increases the reliability of study results (Eckert, 1987, Sale and Ferrell 1988), and enables studies to be conducted at scales that have ecological relevance (Brock et al. 1979, Doherty 1987, Jones 1987b). Monitoring extrinsically marked fish over time, and with growth, enables validation of biocenosis assumptions, estimation of population parameters, assessments of ontogenetic changes, and analyses of cohorts (Jones 1990), even for species with protracted or multiple settlements. Models based on these comprehensive elements, and evaluated over temporal scales relevant to the longevity of the species, are required to explain community structure and population dynamics in reef fishes (Jones 1987a, 1990).

The reliability of the tag retention results of this study is based on the assumption that normal growth and tissue development in the experimental fishes produced natural rejection or retention reactions to the implanted micro-tags. The growth of the juvenile *Sebastes* held in the research tanks with normal ambient water temperatures, validates simulation of natural conditions. Love et al. (1991) reported growth rates among 20 species of young-of-the-year (YOY) rockfishes, from laboratory and field studies, of 0.12 to 0.72 mm $d^{-1}$. The growth rate for juvenile Puget Sound rockfish in Group Rf 1 was 0.08 mm TL $d^{-1}$ (Table 1.1), however, this species is relatively small (maximum length approximately 180 mm TL) for *Sebastes* (Moulton 1975). The growth rates for Group Rf 2 (93% juvenile copper, quillback, and brown rockfish) and for juvenile copper and quillback rockfish in Group Rf 3, were 0.15 and 0.18 TL mm $d^{-1}$, respectively (Table 1.1). These compare favorably with growth rates of 0.15 and 0.20 mm $d^{-1}$ reported for YOY copper rockfish (Love et al. 1991).

The CWT and VIF tag systems, and their application procedures, had no obvious direct effects on survival and growth. This is demonstrated by excellent long-term survival and substantial growth of the juvenile rockfishes in Groups Rf 1, Rf 2, and Rf 3. The lack of any direct negative effects from the internal micro-tags in this study, is comparable to studies with CWT in salmonids (Isaksson and Bergman 1978), where handling and anesthetizing during tagging have been shown to be the major factors in any reduced survival (Canada Department of Fisheries and Oceans, unpublished). Recent advances in the materials used for the VIF tags now make this tag available in a soft silicon format, which has improved the ease of application of this tag in juvenile fishes. The new VIF elastomer tags have been successfully tested in nine species (covering six families) of coral reef fishes, as small as 8 mm standard length (Frederick, in press).

The utility of the CWT system for individual and batch marking juvenile rockfishes is verified by 100% long-term tag retention, in anatomically defined locations (cheek and nape) that enabled accurate detection of the magnetic tags. The constraint of sacrificing fish to recover CWT may be overcome by shallow implantation, allowing benign excision of tags, re-tagging, and re-release of captured fish (Haw et al. 1990), but this concept has not been tested in *Sebastes*.

The VIF tag system was successfully applied to juvenile rockfishes, both in terms of tag retention (92.7% at 132 d in Group Rf 3) and visual tag recovery underwater without physically recapturing the marked fish. The VIF tag can be used both as an external indicator for an internal CWT (Bergman et al. 1968), and for batch marking through the use of different anatomical tag locations (Buckley et al. 1994, Beukers et al. 1995). The micro-size of the VIF tag, and the limited penetration of natural UV-A wavelengths (i.e., 365 nanometers) in sea water (Thurman 1981, Sverdrup et al. 1961) to fluoresce the tag, indicates little potential for the VIF tag to increase predation through visual signals. There may be a need for further research, however, as some freshwater fishes can "see" in the near-UV spectrum (Loew and McFarland 1990). It is also possible, but not demonstrated, that some coral reef fishes have UV vision, because UV-A light is abundant in clear seas (McFarland 1986,1991).

The CWT and VIF tag systems are both physically small and obscure when applied to juvenile *Sebastes*, but they have physically large recovery potential (CWT - magnetic field, and VIF tag - external illumination), and large capacity for data retrieval from recoveries of marked fish. These attributes answer the needs of a marking system to distinguish specific groups of juvenile *Sebastes*. The need for these studies is well acknowledged; little is known about natural mortality rates in the often small and inconspicuous juvenile reef fishes (e.g., coral reef fishes - Victor 1986; temperate reef fishes including *Sebastes* - Love et al. 1991) which could potentially determine the dynamics of the populations. There are limited good data on the spatial and temporal variability of predation, which is considered by some to be the most important source of mortality for juvenile reef fishes (Doherty and Williams 1988b, Hixon 1991). Mortality rates can vary considerably among species of marine fishes (Eckert 1987, Shulman and Ogden 1987) and habitats (Aldenhoven 1986, Behrents 1987). Expansion of experimental parameters in biological and ecological studies to include more species, habitats, and ecologically relevant scales, through marking fish under study with internal micro-tags, would significantly reduce present extrapolations of results from small-scale systems, to ecosystems (Doherty 1991).

# CHAPTER 2: RECRUITMENT OF JUVENILE *SEBASTES MALIGER* AND *S. CAURINUS* IN ARTIFICIAL REEF AND NATURAL BENTHIC HABITATS IN NORTHCENTRAL PUGET SOUND.

## INTRODUCTION

The 26 species of *Sebastes* recorded from Puget Sound and the San Juan Archipelago, Washington (Miller and Borton 1980; Table 2.1) are found in virtually all natural habitats in these non-oceanic waters, although most of the nearshore species have preferences for rocky habitats with macrophyte communities (Haldorson and Richards 1987, Kendall and Lenarz 1987, Mathews 1990, Doty et al. 1995). The abundance of larval *Sebastes* has been noted in early plankton surveys in Puget Sound (Waldron 1972), but there is virtually no information on the ecology of larval or pelagic juvenile life stages in these waters. The potentially significant dispersal of these pelagic stages away from the adult habitats, which is common in *Sebastes* (Love et al. 1991, Moser and Boehlert 1991), could have significant impacts on the replenishment of local populations in Puget Sound, if prevailing oceanographic conditions do not favor retention within the region. This lack of information during the pelagic phases makes it difficult to evaluate inter-annual temporal and spatial variability in the recruitment of juveniles to nearshore habitats.

The transition of juvenile *Sebastes* from the nekton to substrate associated recruitment in specific nearshore habitats in Puget Sound has received little study (Carlson and Straty 1981). Based on investigations of recruitment of similar and the same species of *Sebastes* in other regions, it can be anticipated that mortality during this period strongly influences the numbers of adults in local

Table 2.1. Species of *Sebastes* recorded in Puget Sound (PS) and the San Juan Archipelago (SJA), including eastern Strait of Juan de Fuca.

| *Sebastes* | Rockfish | Recorded[1] | | | Managed |
|---|---|---|---|---|---|
| species | common name | PS | SJA | PS AR[2] | species[3] |
| *aleutianus* | rougheye | X | X | | |
| *alutus* | Pacific Ocean perch | | X | | |
| *auriculatus* | brown | X | X | X | |
| *babcocki* | redbanded | X | X | | |
| *brevispinis* | silvergray | X | X | | |
| *caurinus* | copper | X | X | X | X |
| *camrei* | darkblotched | X | X | | |
| *diploproa* | splitnose | X | X | | |
| *elongatus* | greenstriped | X | X | | |
| *emphaeus* | Puget Sound | X | X | X | |
| *entomelas* | widow | | X | | |
| *flavidus* | yellowtail | X | X | X | X |
| *helvomaculatus* | rosethorn | | X | | |
| *maliger* | quillback | X | X | X | X |
| *melanops* | black | X | X | X | X |
| *miniatus* | vermilion | | X | | |
| *mystinus* | blue | | X[4] | | |
| *nebulosus* | China | | X | | |
| *nigrocinctus* | tiger | X | X | | |
| *paucispinis* | bocaccio | X | X | X | X |
| *pinniger* | canary | X | X | | X |
| *proriger* | redstripe | X | X | | |
| *rosaceus* | rosy | X | | | |
| *ruberrimus* | yelloweye | X | X | X | X |
| *saxicola* | stripetail | X | | | |
| *zacentrus* | sharpchin | X | X | | |

[1] From Miller and Borton 1980; X = species present.

[2] Puget Sound artificial reef.

[3] Harvests managed in non-ocean waters (Pedersen and DiDonato 1982).

[4] Questioned identification from 1918.

habitats, and that the availability of refuge habitats affects these recruitment processes (Hobson and Chess 1976, Carr 1983, Haldorson and Richards 1987, Carr 1991, Love et al. 1991). The larvae, juveniles, and smaller-sized adults of many species of *Sebastes* have significant trophic value for a variety of piscivors (see Ecological Importance of *Sebastes*), and many of the sub-adult and adult *Sebastes* found in Puget Sound are important predators and competitors in nearshore ecosystems (Buckley and Hueckel 1985, Hueckel and Buckley 1987; Rosenthal et al. 1988, Murie 1991). Many of these species may have major functions in structuring biodiversity and promoting energy transfer in benthic habitats in Puget Sound (Simenstad et al. 1977, Hallacher and Roberts 1985, Rosenthal et al. 1988, Hixon 1991).

## Northcentral Puget Sound

The Dissertation research presented here was conducted in northcentral Puget Sound. This region is the 42 km south to north reach of the main Puget Sound basin, bounded on the south by West Point (47°39′45″N) on the eastern shoreline at Seattle, and on the north by Camano Head (48°15′30″N) at the southern end of Camano Island, north of Everett on the eastern shoreline (Figure 2.1). In this region, the width of the main basin ranges from 4.6 km at West Point, to 14.4 km at Possession Point (47°54′15″N) at the southern of Whidbey Island, where the main basin divides into Admiralty Inlet to the northwest and Possession Sound to the northeast. Admiralty Inlet is the major connection between Puget Sound with the Strait of Juan de Fuca. Admiralty Inlet is 6.1 km wide at the southern end near Possession Point, and the width of Possession Sound ranges from 3.3 km at Elliott Point (47°57′N) on the eastern shoreline, to 6.1 km at Camano Head. The surface area of the northcentral region of Puget Sound is approximately 250 km$^2$.

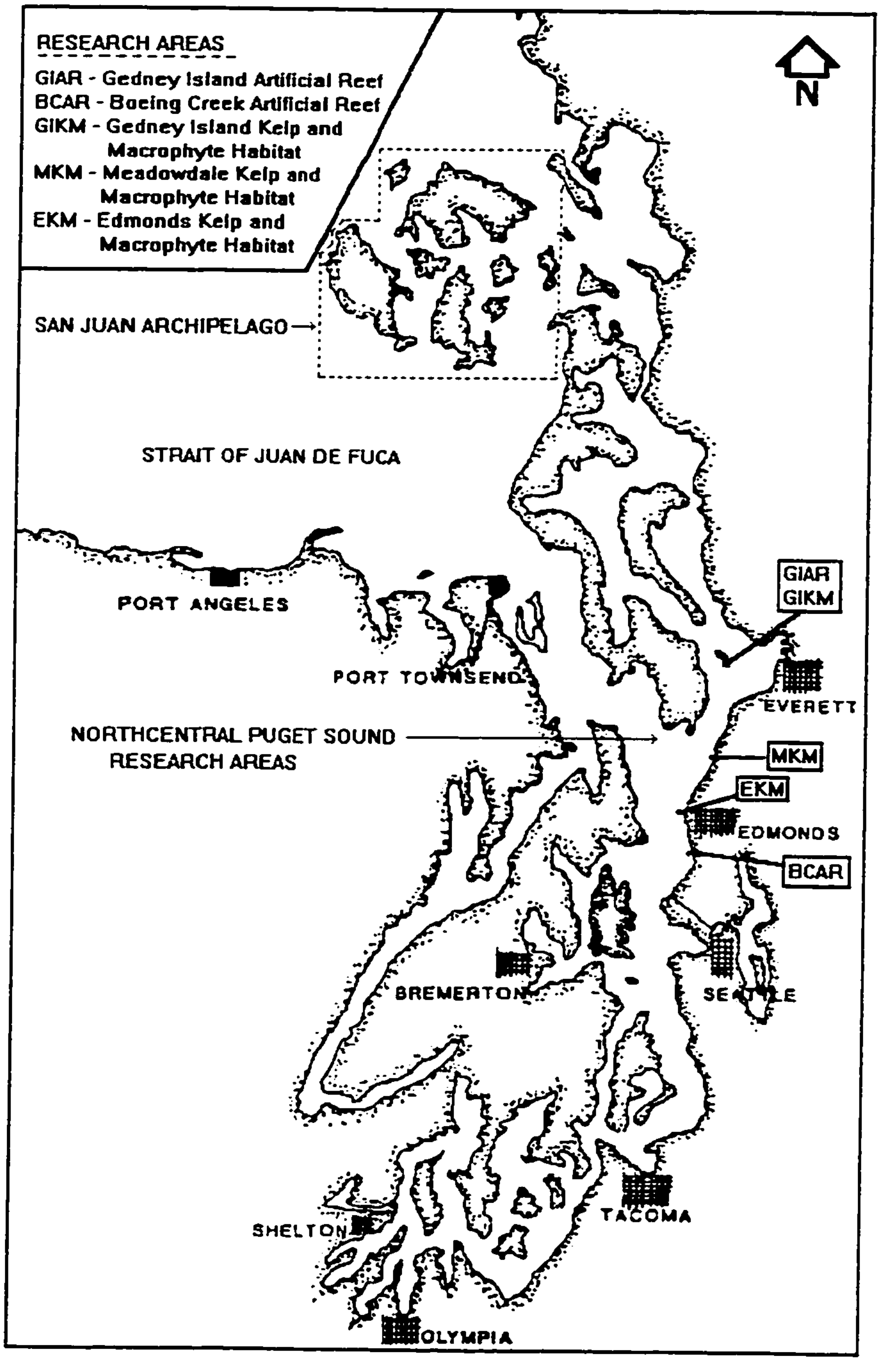

Figure 2.1. Puget Sound artificial reef habitat and natural habitat research locations.

The main basin of Puget Sound is a fertile ecosystem, with abundant phytoplankton and zooplankton resources, and extensive mixing of surface and benthic waters caused by tidal currents, changes in bottom topography, and several major sources of freshwater runoff (Strickland 1983). The strong tidal currents in Admiralty Inlet account for virtually 100% of the salt water exchange in Puget Sound (E.D. Cokelet, NOAA Pacific Marine Environmental Laboratory, personal communication), and create a major mixing zone in the Possession Point area (Cokelet et al. 1991). In the northcentral region, tidal exchanges range from +3.5 m to -1.4 m mean-lower-low-water (MLLW), and depths range from -150 m to -225 m MLLW in the central part of the basin. The long-term mean circulation pattern of Puget Sound is predominately two layered, with water flowing into the basin from Admiralty Inlet in the bottom layer, and out of the basin through the Admiralty Inlet in the top layer; there is little mixing of these water masses except in distinct zones created by sills and constrictions (Cokelet et al. 1991). The tidal current mixing zone in the Possession Point area causes a significant amount of the surface water to be refluxed downward into the lower layer flowing into Puget Sound, recirculating some water and creating a flushing time for the northcentral basin of from six months (E.D. Cokelet, NOAA Pacific Marine Environmental Laboratory, personal communication) to at least one year (Anon. 1984). Large tidal exchanges transport some of the surface water in Admiralty Inlet into Puget Sound (McGary 1977, Anon. 1984), but the net flow annual in the upper 30 m of water is out of the basin; however, northerly surface winds can significantly restrict this water movement (Strickland 1983) and induce currents at 100 m depths equivalent to 0.6% of the wind speed (Anon. 1984).

Surface temperatures and salinities are temporally and spatially variable in Puget Sound due to numerous sources of freshwater runoff. In the northcentral region, the Snohomish River enters Possession Sound at 48°N and often creates a surface lens of reduce salinity and turbid water up to 4.5 m thick. During extreme flooding conditions, the large volume of runoff can result in extreme mixing of fresh water and marine water, and reduce salinity and increase turbidity for short periods down to depths of -12 m MLLW (e.g., November 15, 1995, author, personal observation). In areas of the northcentral Puget Sound region removed from direct runoff impacts, sub-surface (i.e., 0.3 to 5 m below the surface) annual temperatures and salinities range from about 6.5 to 18 degrees Celsius (° C), average 10° C, and 25.2 to 30.6 parts per thousand ($^{0}/_{00}$), average 28 $^{0}/_{00}$, respectively (Collias and Barnes 1966, Thom and Albright 1990). The average annual temperatures at deeper depths (-8 to -20 m MLLW) show somewhat the same range; 7.1 to 12.8 °C, average 9.7 °C (Mathews 1988).

At depths from shallow subtidal to approximately -8 m MLLW, substrates in the northcentral Puget Sound area are composed of expanses of either coarse sand or rocky substrates grading from gravel and cobble; concentrations of larger rocky-reef materials are found dispersed throughout both types of substrates. At depths beyond -8 m MLLW, the substrate usually varies from firm coarse sand, to mud, with some areas of firmer materials ranging from hard clay to solid aggregates. The rock substrates within the photic zone usually support dense communities of annual and perennial macrophytes, including *Laminaria saccharina*, *Costaria costata*, *Agarum* sp., *Desmerestia* sp., and a variety of folious turf red algae, which often form the understory community of macrophytes in beds of the canopy-forming, annual macrophyte, bull kelp, *Nereocystis luetkeana*. Expanses of sand substrate in shallow water often have dense beds of the perennial flowering seagrass, eelgrass, *Zostera marina*. The macrophyte and seagrass communities in the Puget Sound basin are known to have dynamic seasonal and spatial fluctuations in biomass in response to the natural physiology of the plants, irradiance levels, and temperature and nitrate concentrations in the surrounding waters (Hodgson and Waaland 1979, Thom and Albright 1990).

## Artificial Reefs in Puget Sound

Artificial reef structures have been used throughout the Puget Sound basin since 1975 by the Washington State Department of Fish and Wildlife (formerly the Department of Fisheries) to enhance the amount of rocky-reef habitats in nearshore waters (Buckley 1985, Buckley and Hueckel 1985, Hueckel and Buckley 1987, Buckley 1989). The sites selected for the artificial reefs were based on the presence of indicator biota (Hueckel and Buckley 1989) which predict the potential for development of rocky-reef associated organisms. Construction of these artificial reefs involved dumping relatively large materials from surface barges, which resulted in reef-module piles ranging from 1 to 5 m high, and reef substrates of primarily large-sized crevice habitats. Rapid successional development of sessile biota on the artificial reefs transformed the new benthic substrates into mimics of natural rocky-reef communities and habitats, usually within three to five years (Buckley and Hueckel 1985, Hueckel and Buckley 1989). Intensive surveys of these artificial reefs over eight years determined that large numbers of sub-adult and adult *Sebastes* (standing stock estimates often over 1.0 fish $m^{-2}$; Buckley and Hueckel 1989) use the artificial reef habitats for foraging (Hueckel and Stayton 1982, Hueckel and Buckley 1987), shelter, and orientation (Buckley 1982, Buckley and Hueckel 1985). Two of these artificial reefs in the northcentral Puget Sound region, Boeing Creek

Artificial Reef (BCAR) and Gedney Island Artificial Reef (GIAR; Figure 2.1), are used as study sites in the Dissertation research presented here.

Current world-wide research on artificial reefs has recognized that reef habitat features for recruitment and survival of juveniles are especially important to meet the life history requirements of individual species (Bohnsack and Sutherland 1985, Seaman et al. 1989, Bohnsack et al. 1991, Seaman and Sprague 1991). To develop the proposal for the Dissertation research presented here, four artificial reefs in Puget Sound were qualitatively surveyed to determine the characteristics of the reef substrates that would potentially benefit the recruitment and survival of juvenile *Sebastes*. These surveys determined (1) that the large-sized materials used for reef construction formed limited amounts of small-sized crevice habitat in the reef substrate, (2) that the small-sized crevice habitat on the artificial reefs resulted primarily from small-sized materials mixed in with large scrap concrete and quarry rock, (3) that juvenile *Sebastes* took refuge in small-sized crevice habitats in the artificial reef substrates when disturbed, and that larger rockfishes often preyed upon juveniles that were forced out of these refuge habitats, and (4) that recruitment and refuge habitats for juvenile *Sebastes* appeared to be limited on Puget Sound artificial reefs (Washington Department of Fish and Wildlife, unpublished).

## Pilot Study of Refuge Habitat Parameters

A pilot study was conducted on BCAR in November 1990 to develop the design of the study sites used in the Dissertation research presented here. The objective of this pilot study was to develop criteria for enhancing the amount of refuge habitat for juvenile *Sebastes* on BCAR and GIAR, where recruitment and survival of juveniles could be affected by refuge habitat limitations.

Substrate associated juvenile *Sebastes* are thought to be subjected to predation primarily from piscivorous fishes and birds (Love et al. 1991). Intuitively, increased protection from these predators for the smaller-sized juveniles would result from retreating into crevices (refuge habitats) which had small openings and sufficient depths to place the juveniles beyond the predator's "reach" (Lively 1988). It was probable that BCAR and GIAR were limited in the amount of optimal refuge habitat for survival of juvenile *Sebastes*, and that adequate refuge habitat on artificial reefs would result in enhanced survival of juveniles on the reefs through reduced predation, and non-emigration to less suitable habitats.

Surveys for this pilot study were conducted using simple random sampling to quantify the relationships between (1) the sizes of rocks and concrete rubble (hereafter collectively termed rocks) on the reef, and the sizes of the crevices formed by these rocks, and (2) the juvenile *Sebastes* sizes, and the sizes of the crevices habitats they occupied. The sizes of the rocks, and the dimensions of the crevice habitats they created, were measured using calipers; any juvenile *Sebastes* in the crevice habitats were captured for length and weight determinations.

The pilot study sample size that related rock size and crevice size ($n = 33$) was sufficient to examine this relationship, but lacked data from the small-sized rocks that were expected to form juvenile *Sebastes* refuge habitats; there was little of this sized material on any of the artificial reefs. However, the significant positive correlation between average rock size and related crevice-opening size (correlation coefficient - CC; $r = 0.888$, $p < 0.001$; see Data Analyses Methods; Figure 2.2) verified qualitative survey information that larger-sized rocks on the reefs formed predominately larger-sized crevice habitats. The significant positive correlation between average rock size and related crevice volume was equally informative (CC; $r = 0.888$, $p < 0.001$) for determining the sizes of reef materials needed for developing refuge habitats. These relationships were considered sufficiently accurate to estimate the sizes of the materials needed for construction of small-sized crevice habitats on artificial reefs.

The pilot study sample size that compared juvenile *Sebastes* and the crevice habitats they occupied was small ($n = 11$), however, the significant positive correlations between crevice-opening size and the lengths (CC; $r = 0.667$, $p = 0.025$; Figure 2.3a) and weights (CC; $r = 0.667$, $p = 0.025$; Figure 2.3b) of the juvenile *Sebastes* in the crevices, gave a strong indication that juveniles seek refuge in crevices with openings that are proportional to their body sizes.

Although it was not possible to develop a predictive relationship between rock size and related crevice size from the data in this pilot study, especially for crevices with openings <15 $cm^2$, the information gained was sufficient to estimate that small-sized, angular shaped rocks dumped from surface barges would create a reef substrate with a range of sizes of small crevice habitats. Examination of the quarry rock materials readily available from commercial sources determined that crushed, graded quarry rock between 10-20 cm diameter would be the optimal material to create the desired reef substrate. It was also determined that the small-sized quarry rock should be dispersed in the artificial reef areas in low profile strips of substrate, approximately 0.25 m thick, to maximize the densities of the crevice habitats. Earlier surveys of the densities of sub-adult and adult *Sebastes* on BCAR and GIAR (Buckley and Hueckel

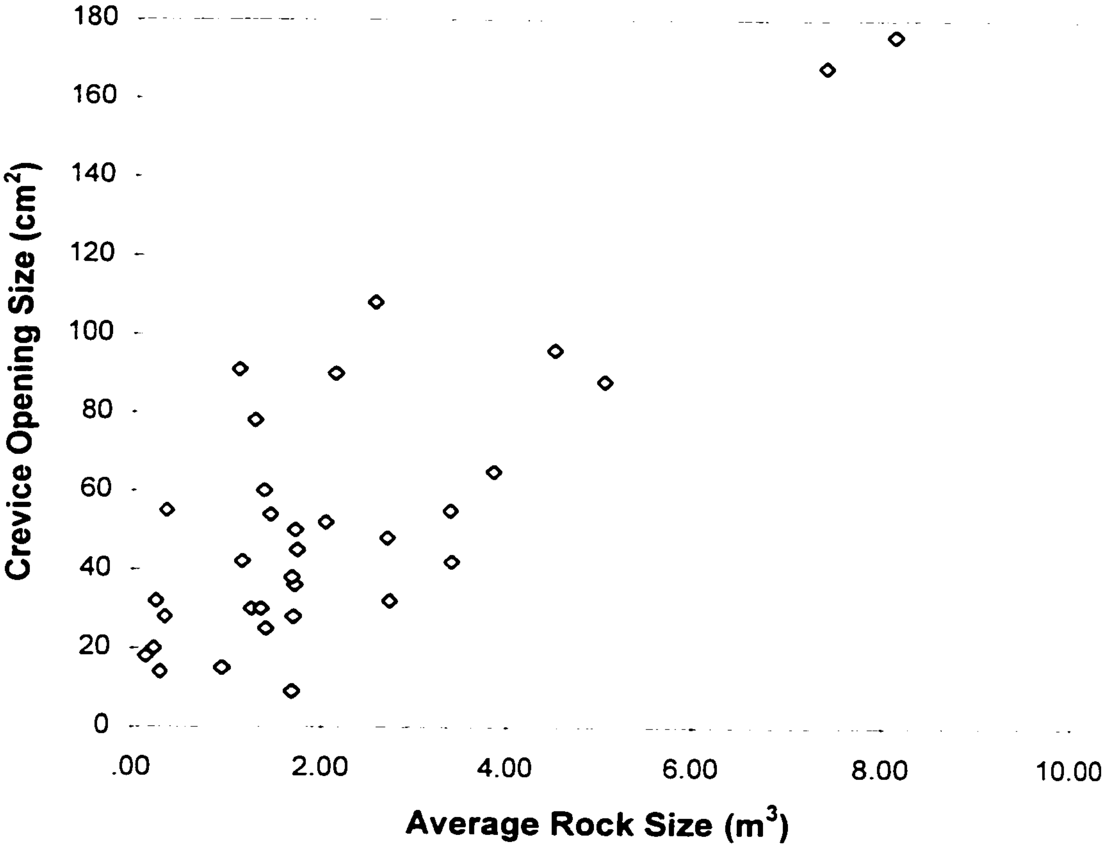

Figure 2.2. Relationship between average rock size and crevice-opening size, for Boeing Creek Artificial Reef crevice habitat study.

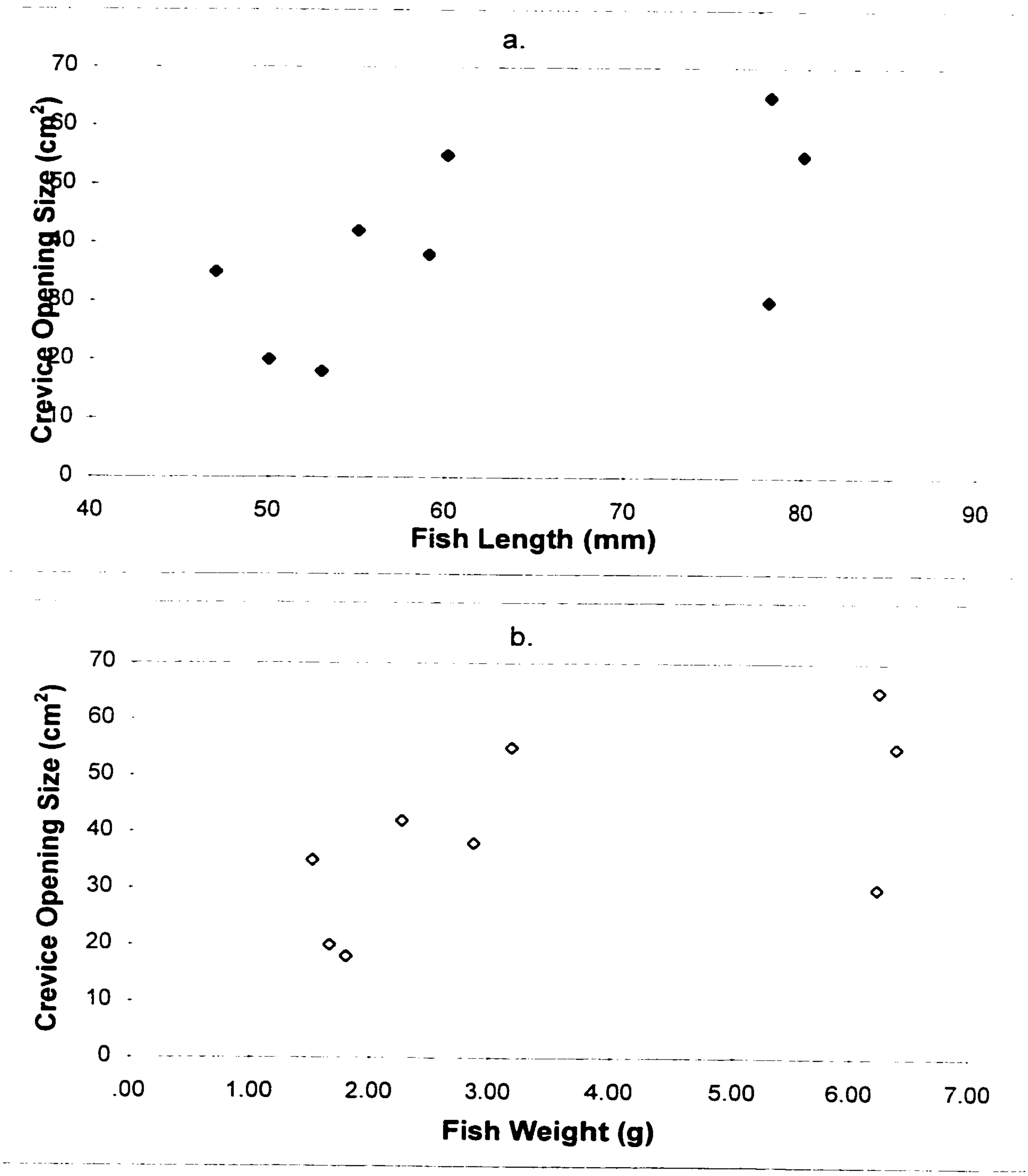

Figure 2.3. Relationships between crevice-opening size and fish length (a) and fish weight (b), for Boeing Creek Artificial Reef crevice habitat study.

1989) had shown that these life stages preferred high profile reef substrate. Based on this selection of preferred habitats, it was anticipated that the low profile design of the reef substrate with crevice habitats for juveniles would also provide for a natural separation of juvenile and later life stages of *Sebastes*. This design incorporated the available information and theories on the recruitment pathways and depths that juvenile rockfishes use when recruiting to rock substrates.

It was determined during the pilot study that the designs of BCAR and GIAR would accommodate the additions of substrates with high densities of the sizes of crevice habitats used by juvenile *Sebastes*, and that differences in the depth contours at these two locations would place this new substrate in two different configurations. This would result in study areas without replication, but replicate designs are often not possible or practical in studies conducted at ecologically relevant scales, and it was decided that scale was the more important parameter (see Study Design and Sampling Methods).

### Juvenile *Sebastes* Recruitment and Refuge Habitat

Information can be gained on the processes possibly affecting the recruitment and survival of juvenile *Sebastes* in Puget Sound by considering the broader theories developed in other ecosystems for juveniles of other species. There have been numerous investigations, primarily in tropical ecosystems, of predation, competition, prey availability, and structural aspects of the substrate, as factors thought to affect recruitment and survival of juvenile reef fishes, with supporting evidence that these factors are probably not mutually exclusive, and are temporally and spatially variable (see Carr 1989, Hixon and Beets 1993). Recent investigations in temperate ecosystems have increased the emphasis on biogenic habitat structure and dynamics (Holbrook et al. 1990a, 1990b, Anderson 1994, Carr 1994a, 1994b, Pihl et al. 1994, Rangeley and Kramer 1995), reef substrate micro-habitat structure (Moreno and Jara 1984, Levin 1991, Norton 1991), and prey availability (Connell and Jones 1991, Levin 1994, Connolly 1994), as factors affecting recruitment and survival of juvenile reef fishes.

For coral reef dominated ecosystems, the availability of refuge habitats (1) has been shown to influence recruitment, (2) is probably a very important factor in post-settlement survival, and (3) is thought to be related to the ability of recruits to invade and persist in adult territories (Sale 1991a); refuge habitat is especially important in relation to the distributions of predators (Shulman 1985, Hixon and Beets 1993). Although comparable information is not available for reef fishes, for juvenile lobsters in temperate and tropical ecosystems, the abundance of refuge habitats in the reef substrate can represent demographic bottlenecks to survival and production (Wahle and Steneck 1991 - American lobster, *Homarus americanus*; Parrish and Polovina 1994 - spiny lobster, *Panulirus marginatus*). The availability of appropriate habitats is important early in recruitment processes, as the highest mortality rates for several coral reef fishes occur within two weeks after settlement (Sale and Ferrell 1988). All of these factors indicate that refuge habitat availability should be very important in recruitment and post-recruitment survival of juvenile *Sebastes* in Puget Sound.

Resources thought to be potentially limiting factors to substrate associated *Sebastes* are food and shelter (Larson 1980), however, no experimental manipulations of these resources have been conducted to verify these conclusions (Love et al. 1991). There is some evidence that high mortality of settling and newly recruited *Sebastes* is due to predation and cannibalism (Hallacher and Roberts 1985, Love et al. 1991), however, survival rates have not been measured, and the validity of the overall importance of cannibalism and intra-generic predation are in question (see Cannibalism and Other Predation). The impacts of predation mortality on post-settlement densities of rockfishes have not been determined, nor has the potential for reducing this mortality through enhanced refuge habitat availability. If interaction between species and life-stages of *Sebastes* is a factor in survival, then appropriate juxtapositions of juvenile and adult rockfish habitats on artificial reefs may result in enhanced survival of juvenile rockfishes by reducing encounters between adults and juveniles, and, therefore, potential predation and competition.

In the Strait of Georgia, north of Puget Sound, habitat type and depth were found to be important influences on distribution patterns of sub-adult and adult copper rockfish (*S. caurinus*) and quillback rockfish (*S. maliger*), with both species abundant on complex rock habitats, copper rockfish being found predominately at shallower depths, and quillback rockfish deeper (Richards 1986, 1987). Small (70 to 190 mm fork length) quillback rockfish were not found at shallow depths (6 to 12 m, relative to mean sea level), and small copper rockfish were not found at deeper depths (12 to 18 m); juvenile rockfishes (<70 mm fork length) were present but not surveyed (Richards 1987). Recently settled juvenile copper rockfish (37 to 48 mm, assumed TL) in the Strait of Georgia demonstrated ontogenetic shifts in the use of a variety of habitats characterized by abundant bull kelp and perennial macrophytes (Haldorson and Richards 1987). These juvenile copper rockfish appeared to vacate bull kelp habitats as these annual plants seasonally decreased in density, and there was a corresponding reduction in refuge habitat availability and/or a reduction in prey densities. In Puget Sound, a mixture of juvenile copper rockfish quillback rockfish, and brown rockfish (*S. auriculatus*) were found in a variety of habitats of bull kelp and perennial macrophytes, and in eelgrass, and vacated those habitats that seasonally lost biogenic structure (i.e., refuge habitat) due to natural processes (Mathews 1990).

Substrate complexity, and the resulting amounts of specific refuge habitats, can be manipulated on artificial reefs by varying the structural characteristics of the materials used for the reef substrates. On artificial reefs in tropical ecosystems, the availability of refuge habitat (i.e., the number and sizes of crevices) was manipulated, and demonstrated that the availability of appropriate refuge habitat is a major factor in recruitment success and post-recruitment survival of juvenile reef fishes (Shulman 1984, 1985, Hixon and Beets 1993). An increase in the number of refuge habitats (i.e., holes) in the artificial reef substrate resulted in an increased number of fish finding suitable habitat on the reef; there was also a positive correlation between the number of small-sized crevice habitats in the artificial reef substrate, and the numbers of small-sized fishes on the reef (Hixon and Beets 1993). Increased predation on small-sized reef fishes was also linked to a reduction in appropriate refuge habitats on artificial reefs in tropical ecosystems (Shulman 1984, 1985), and on artificial habitats in a temperate ecosystem (Behrents 1987). The combined effects of these factors, and habitat selection processes of juvenile reef fishes, have important implications for attempts to enhance recruitment and survival of juvenile rockfishes on artificial reef habitats in Puget Sound.

### Cannibalism and Other Predation

Substrate associated juvenile rockfishes are thought to be subjected to predation from piscivorous fishes, and it is inferred in several studies that cannibalism, or intra-generic predation, is the source of much of this mortality (see review in Love et al. 1991). Other nearshore reef fishes, such as lingcod (*Ophiodon elongatus*), have been identified as potential (Moulton 1977, Haldorson and Richards 1987) and proven (Hallacher and Roberts 1985) predators on juvenile rockfishes, and larger sculpins (Cottidae) are known opportunistic piscivors in reef ecosystems, and known predators on juvenile rockfishes (GIAR, author, personal observation). However, a review of the literature on trophic studies of the species of *Sebastes* found in nearshore habitats in Puget Sound reveals little information to verify the inference of cannibalism, or intra-generic predation for local species. This is particularly true for copper rockfish, quillback rockfish, and brown rockfish, as well as for black rockfish (*S. melanops*) and yellowtail rockfish (*S. flavidus*), which are also often found on BCAR and GIAR.

Trophic analyses were reviewed from seven studies of copper rockfish, six studies of quillback rockfish, and one study of brown rockfish, from Alaska, Puget Sound, the San Juan Archipelago, and California. These studies found only four Puget Sound rockfish (*S. emphaeus*), and one rockfish of unknown species, in 1,073 copper rockfish stomachs, two Puget Sound rockfish in 704 quillback rockfish stomachs, and no rockfish in 44 brown rockfish stomachs (Patten 1973, Prince and Gotshall 1976, Moulton 1977, Hueckel and Stayton 1982, Hueckel and Buckley 1987, Rosenthal et al. 1988, Murie 1991, 1995, NOAA/NMFS Northwest and Alaska Fisheries Center, unpublished). Miller et al. (1977) note that mixed juvenile rockfish and Pacific sand lance (*Ammodytes hexapterus*) formed 16% of the Index of Relative Importance in 52 copper rockfish stomachs in Puget Sound, but the number and species of juvenile rockfish was not given.

Trophic studies of black and yellowtail rockfish from Alaska, Puget Sound, the San Juan Archipelago, and California, confirm the apparent minor or opportunistic role of intra-generic predation in *Sebastes* for Puget Sound species. Analyses were reviewed from four studies totaling 227 black rockfish, and four studies totaling 384 yellowtail rockfish. These analyses found one Puget Sound rockfish and 41 juvenile blue rockfish (*S. mystinis*) in the black rockfish stomachs, and four juvenile rockfish of unknown species in the yellowtail rockfish stomachs (Moulton 1977, Brodeur and Pearcy 1984, Hallacher and Roberts 1985, Rosenthal et al. 1988, NOAA/NMFS Northwest and Alaska Fisheries Center, unpublished). The high incidence of predation on juvenile blue rockfish by black rockfish (41 in 28 stomachs) occurred during a mass settlement, density dependent predation situation, specific to an upwelling cycle in a coastal California ecosystem (Hallacher and Roberts 1985).

These studies indicate that cannibalism, or intra-generic predation, should not be a major source of mortality for juvenile rockfishes in nearshore habitats in Puget Sound. However, this may not be true under situations of mass recruitment, or locally limited recruitment habitat (e.g., on artificial reefs), when density dependent predation may occur.

## OBJECTIVES

The overall objective of the Dissertation research presented in this study was to examine the substrate associated recruitment of juvenile copper rockfish and quillback rockfish in artificial reef and natural benthic habitats in northcentral Puget Sound, in order to compare and contrast recruitment parameters in these different habitats. The general hypotheses were (1) that juveniles of these species of rockfish utilized specific natural habitats with complex substrate characteristics during the juvenile substrate associated recruitment period, and that these habitats were important to juvenile survival and ontogenetic development, and (2) that manipulation of artificial reef substrates could simulate these recruitment habitats, which would enhance recruitment and survival of these juvenile rockfishes in artificial reef areas. The realization of the overall objective would provide information for the enhancement of natural recruitment and survival of these juvenile rockfishes in Puget Sound.

The objectives of this study were to assess substrate associated recruitment of juvenile copper rockfish and quillback rockfish (1) during a 1991 study on Boeing Creek Artificial Reef, (2) during a 1992 study in the Gedney Island natural bull kelp and macrophyte habitat, (3) during a 1993 study in the Edmonds natural bull kelp and macrophyte habitat, and (4) during the 1994 recruitment season on Boeing Creek Artificial Reef and Gedney Island Artificial Reef, and in the Edmonds and Meadowdale natural bull kelp and macrophyte habitats (Figure 2.1). The specific elements of juvenile rockfish recruitment examined in these assessments were (1) spatial and temporal parameters and recruitment pathways, (2) juvenile densities and habitat selection and use, (3) temporal distributions, (4) recruit growth rates, and (5) recruit survival rates. All of these factors are important in clarifying the substrate associated recruitment ecology of juvenile *Sebastes*, and in determining if manipulating nearshore habitats with artificial reef substrates can enhance local natural recruitment and survival of juveniles.

## DESCRIPTION OF STUDY AREAS

The study areas for this research were the Boeing Creek Artificial Reef (BCAR) and Gedney Island Artificial Reef (GIAR), and the natural bull kelp and macrophyte habitats at Edmonds (EKM), Meadowdale (MKM), and Gedney Island (GIKM), which are all located in northcentral region of the Puget Sound basin, primarily along the eastern shoreline (Figure 2.1). These locations were selected as study areas because they were in the region of Puget Sound that previous years studies had shown was most likely to receive settlement of juvenile copper rockfish and quillback rockfish (Washington Department of Fish and Wildlife, unpublished, Doty et al. 1995). Observations of the surface canopies of the bull kelp habitats at Edmonds, Meadowdale, and Gedney Island over several years, had also indicated that these habitats had relatively stable densities of plants in the same areas, from year to year (author, personal observation).

The artificial reefs at Boeing Creek and Gedney Island had the following similarities:

1. Both were constructed from large scrap concrete and quarry rock materials, and they were approximately at the same stage of biological development; their original construction dates were June 1981 - GIAR, and October 1982 - BCAR.

2. Both were of ecologically relevant sizes; BCAR had 6,000 $m^2$ of contiguous reef substrate, and GIAR had 1,665 $m^2$ of clustered reef substrate, with over 1,000 $m^2$ of additional reef substrate in the immediate area.

3. Both had reef substrates at depths ranging from -15 to -30 m MLLW.

4. Both areas were subjected to similar oceanographic and atmospheric parameters; except GIAR experienced seasonal events of lowered surface, and rarely benthic, salinity due to freshwater runoff.

5. Both were adjacent to natural macrophyte and/or eelgrass habitats.

6. Both were constructed on compacted sand substrates which surround the reef substrates with open sand habitat.

7. Both had established populations of sub-adult and adult copper rockfish and quillback rockfish.

In March 1991, 635 metric tons of small-sized quarry rock were added to both the BCAR and GIAR areas to form recruitment substrates with abundant crevices for refuge habitats. The design for the refuge substrates divided the quarry rock into new substrate adjacent to the original artificial reef (adjacent recruitment habitat - ARH; the Integrated Reef of West et al. 1994), and new substrate isolated from the original artificial reef (isolated recruitment habitat - IRH; the Isolated Nursery Reef of West et al. 1994; Figures 2.4 and 2.5). The differences in depth contours and distances between the artificial reef substrates and the nearshore natural habitats at BCAR and GIAR, resulted in two strips of refuge substrate approximately perpendicular to the shoreline (east and west habitats) for both the ARH and IRH at GIAR, and three strips of refuge substrate approximately perpendicular to the shoreline (north, central, and south habitats) for both the ARH and IRH at BCAR. These strips of refuge substrate within each

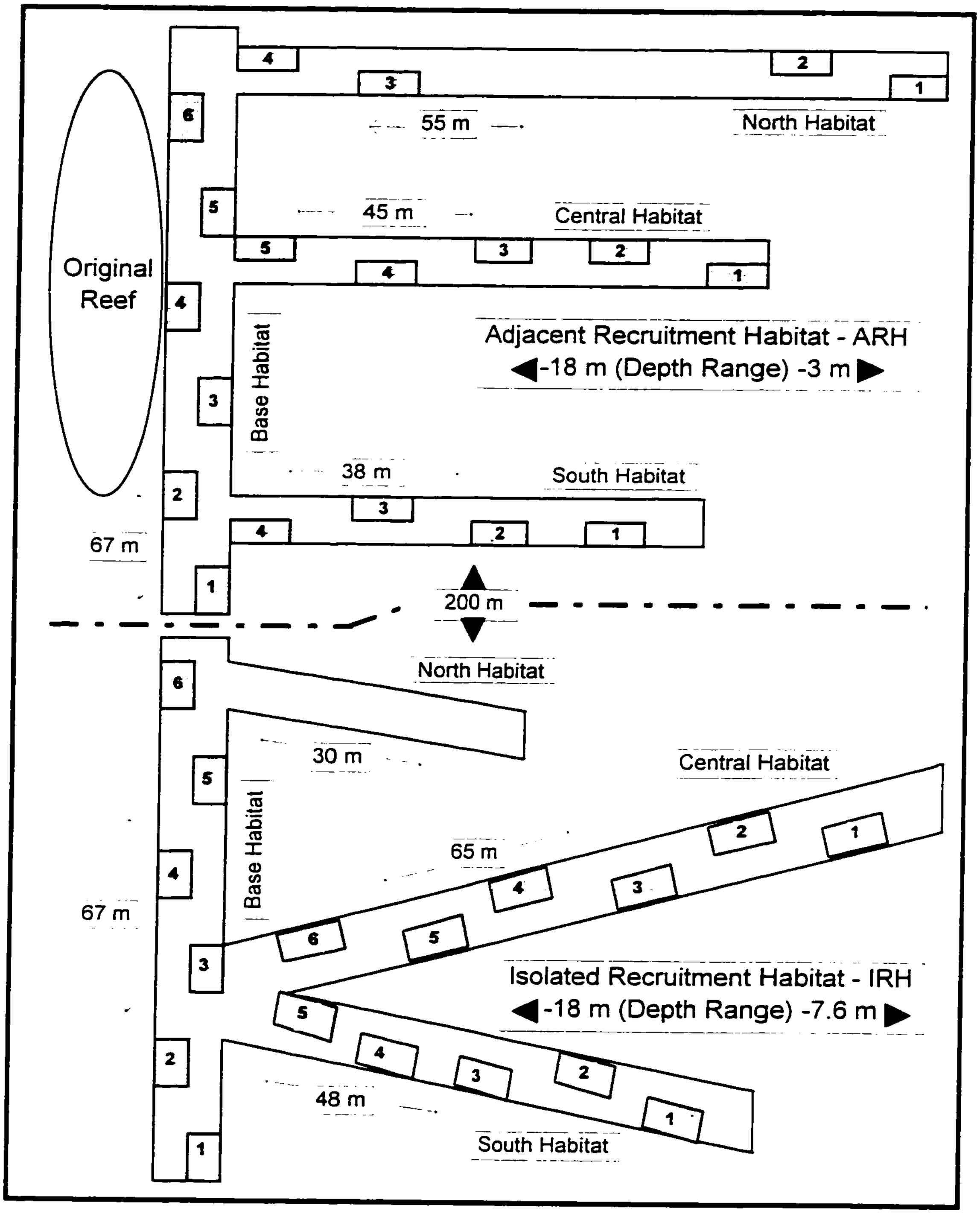

Figure 2.4. Plan view of Boeing Creek Artificial Reef adjacent and isolated recruitment habitats with survey quadrate locations.

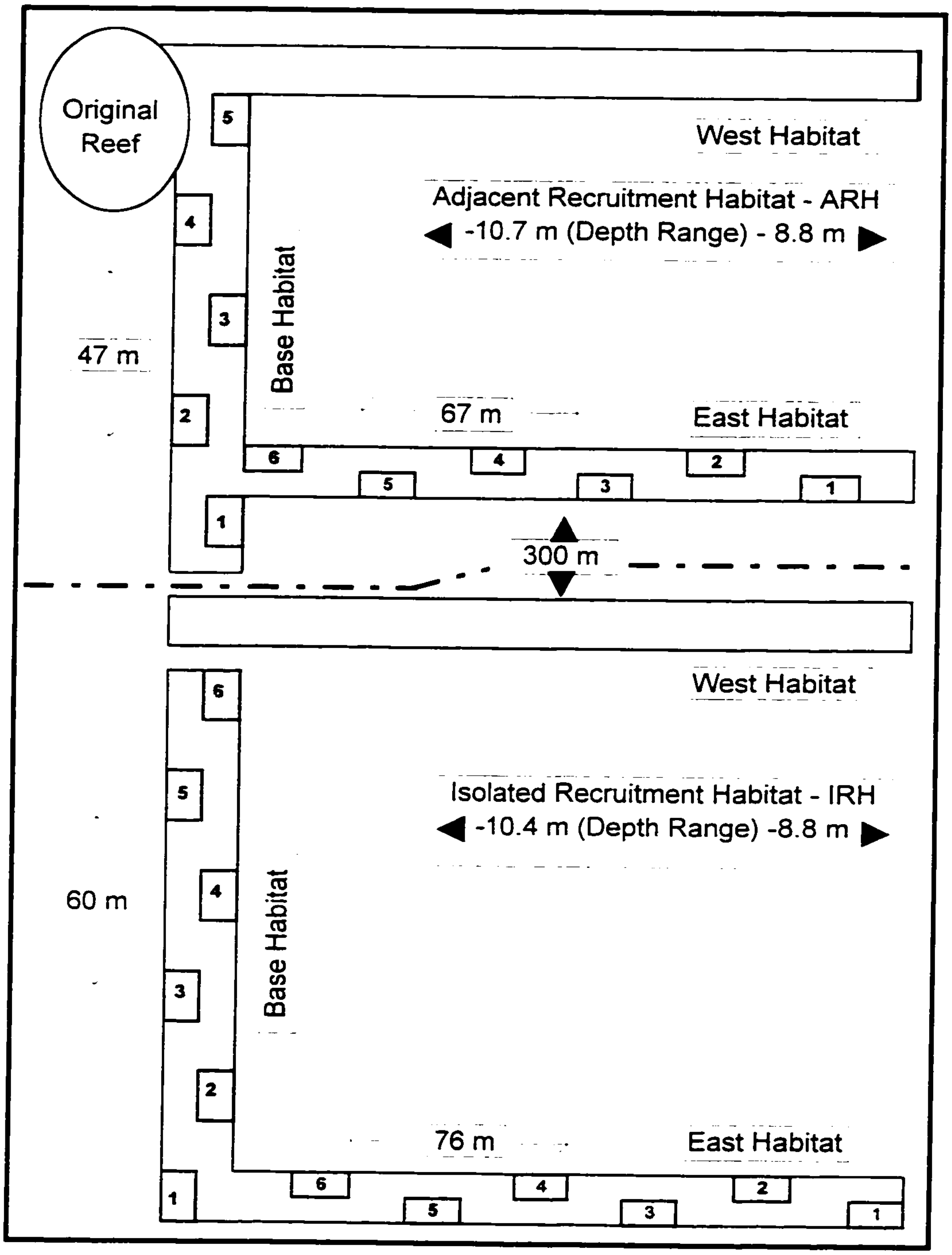

Figure 2.5. Plan view of Gedney Island Artificial Reef adjacent and isolated recruitment habitats with survey quadrate locations.

ARH and IRH were connected at the offshore ends by strips of the same type of substrate approximately parallel to the shoreline (base habitats).

The spatial separations of the ARH and IRH pairs were approximately 200 m at BCAR and 300 m at GIAR. At BCAR, the north, central, and south habitats of the ARH and IRH were constructed on a benthic substrate that sloped an average of 30° nearshore to offshore; at GIAR the east and west habitats were on a benthic substrate that sloped approximately 5° nearshore to offshore.

The natural bull kelp and macrophyte habitats at Gedney Island, Meadowdale, and Edmonds all formed bands of nearshore habitat that were essentially parallel to the shoreline. Although there was some variability in the densities of plants between years, the dimensions of these habitats were similar each year because they are spatially limited by the availability of rocky substrate for attachment of the bull kelp and other macrophytes. EKM was approximately 330 m long, 60 to 75 m wide at the ends, and 105 m wide in the middle, covering approximately 26,950 $m^2$. MKM was approximately 700 m long, varied between 50 to 75 m wide, and covered approximately 43,750 $m^2$. GIKM was approximately 1,100 m long, varied between 75 to 150 m wide, and covered approximately 135,000 $m^2$. These natural habitats had the following similarities:

1. The bull kelp and macrophytes were between the -3 to -8 m MLLW depth contours.

2. The substrate was mainly compacted sand and gravel, with protruding, rounded and angular rocks up to 0.5 m in diameter.

3. The vertical relief of the rocky substrates was predominately <0.25 m, with occasional larger rocks up to 1.0 m in diameter.

4. The fronds of the bull kelp formed dense, relatively continuous canopy habitat, and the stipes were entwined forming clusters of complex habitat extending from the surface to the substrate.

5. The dense understory macrophyte community was composed primarily of a mixture of brown alga, folious red alga, and green ulviods common to shallow nearshore vegetated habitats in Puget Sound (Hodgson and Waaland 1979, Thom and Albright 1990, Doty et al. 1995).

6. The bull kelp and macrophyte communities were virtually eliminated each winter with the natural seasonal deterioration of the plants, and the detached vegetation formed benthic drift habitat that was moved out of the area by tidal currents.

## JUVENILE *SEBASTES* RECRUITMENT STUDIES IN PUGET SOUND

Intensive studies of the ecology and habitat use of substrate associated juvenile copper rockfish, quillback rockfish, and brown rockfish, in nearshore habitats in Puget Sound, were conducted from 1991 to 1993 by the Washington State Department of Fish and Wildlife. These studies were directed at (1) documentation and protection of natural habitats that were settlement and nursery areas for juvenile *Sebastes* (Doty et al. 1995, Washington Department of Fish and Wildlife, unpublished), and (2) assessments of the ecology and habitat use of juvenile *Sebastes* associated with artificial reef nursery habitats (West et al. 1994, West et al. 1995). The author of this Dissertation participated in these studies as Principal Investigator, and information from these studies, especially relating to artificial reef substrates, contributed to the Dissertation research presented here.

Surveys of natural habitats in central Puget Sound for juvenile copper rockfish, quillback rockfish, and brown rockfish, during August through November in 1991 and 1992, found juveniles primarily along the northeastern shoreline, indicating oceanographic factors in this region may have induced a strong spatial component to settlement during these years (Doty et al. 1995). The nearshore habitats along the western shoreline in this region are known to be structurally similar to habitats along the northeastern shoreline, and juvenile *Sebastes* have been found there in previous years (Mathews 1988). This indicates that there may be an inter-annual variability component to juvenile *Sebastes* settlement in this region. Juvenile *Sebastes* appear to settle in Puget Sound habitats with the greatest biogenic structural complexity, and therefore the habitats with the highest refuge potential (Doty et al. 1995). The variability in settlement of juveniles may be related to variability in the densities of bull kelp and other macrophytes in Puget Sound, which naturally fluctuate on seasonal, annual, and spatial scales (Hodgson and Waaland 1979, Thom and Albright 1990).The availability of preferred food items may also be a factor in the choice of settlement habitats (Levin 1994).

Surveys of BCAR and GIAR habitats for juvenile copper rockfish, quillback rockfish, and brown rockfish began with qualitative surveys in April 1991, one month after the ARH and IRH substrates were constructed at these artificial reef sites. Quantitative surveys were started in October 1991, when the first substrate associated juvenile *Sebastes* were found on BCAR (West et al. 1994), approximately 210 d after construction. This first recruitment was to the new substrates prior to the development of macrophyte communities, and the juveniles actively used the small-sized crevices as refuge habitats. The densities of juvenile rockfishes (copper, quillback, and brown rockfish combined) were greater on the IRH, than on the ARH; the juveniles on the ARH were also found primarily at shallower depths, away from the deeper adult rockfish habitat. These results demonstrated that the ARH and IRH substrates with abundant crevices provided refuge habitat for juvenile *Sebastes*.

By 1992, the shallower portions of the new substrates at BCAR had developed communities of bull kelp, brown algae (i.e., *L. saccharina*, *Agarum fimbriatum*, *C. costata*, and *Desmarestia ligulata*), and foliose red algae (i.e., *Rhodymenia pertusa*, *Gigartina exasperata*, and *Sarcodoitheca* sp.), similar to the macrophyte communities in natural habitats in the same region of Puget Sound (Doty et al. 1995, West et al. 1995). The new substrates at GIAR developed similar macrophyte communities in 1993, but at lower densities, except bull kelp was absent as the depth of the new substrate (>-12 m MLLW) was beyond the normal depth range for this macrophyte. In 1992, when communities of macrophytes were present on BCAR, juvenile rockfishes (copper, quillback, and brown rockfish combined) recruited to BCAR earlier in the season, at a smaller size, and over a shallower depth range (i.e., the depth range of the macrophytes), than in 1991. Recruitment of juvenile rockfishes on BCAR and GIAR in 1992, differed by substrate type; the densities of juveniles were highest on the IRH, followed by ARH, and were lowest on the original artificial reef (i.e., the adult habitat; West et al. 1995). In 1992, juvenile rockfishes demonstrated a strong association with macrophytes as refuge habitat, similar to the behavior of juveniles on natural habitats in Puget Sound.

Juvenile rockfishes from the 1992 cohort remained on BCAR substrates when the abundance of annual macrophytes declined due to normal seasonal processes (West et al. 1995). This contrasted the findings of surveys in natural habitats in Puget Sound, where juvenile rockfishes vacated nearshore habitats (at similar depths) with seasonal losses of the macrophyte refuge habitats (Doty et al. 1995). The rocky substrates of the natural habitats were composed primarily of dispersed, rounded rocks, which did not form abundant crevices, and, therefore, had low refuge habitat potential without the additional structural complexity of the macrophytes. Qualitative observations on BCAR and GIAR in 1991 and 1992 indicated that juvenile rockfishes remained primarily deep within the crevices in the artificial reef substrates during the winter months, in an apparent state of inactivity or torpor, and that the juveniles were active and feeding during the fall and late spring periods.

## STUDY DESIGN AND SAMPLING METHODS

The overall goals of the study design and the sampling methods used in this research were to provide quantified information for (1) determination of the substrate associated recruitment ecology of juvenile copper rockfish and quillback rockfish in the "natural scale" nearshore habitats at BCAR, GIAR, EKM, MKM, and GIKM, and (2) assessments of enhanced recruitment and survival of these rockfishes at BCAR and GIAR. A holistic approach allowed broad contrasts and comparisons between study areas, and compared selected attributes within some study areas for their affects on substrate associated recruitment of these rockfishes. The intent of this study was to investigate how these nearshore ecosystems functioned in the recruitment process, in order to clarify substrate associated recruitment ecology of juvenile rockfishes, and to determine how large scale manipulations of the substrate in some study areas would affect this recruitment.

The study design was based on a sampling scheme, as opposed to a controlled or manipulative experiment (Eberhardt and Thomas 1991), to study the uncontrolled events of the substrate associated recruitment processes. The only fixed elements were the time, place, and method of observation, or sampling, of the populations within the natural scale study areas. The substrate manipulations were experiments on limited parts of the ecosystems where the recruitment processes operated; these experiments were designed to increase the amount of crevice or refuge habitat for juvenile rockfishes. The sampling scheme included both descriptive and analytical sampling (*sensu* Cochran 1977); descriptive sampling for efficient estimation of parameters of the populations within the study areas, and analytical sampling for inferences about differences among subgroups of the populations in some study areas. However, the inferences were based on sampling of unreplicated study areas and experiments (see Spatial and Temporal Scale) and, therefore, the inferences were limited in scope to within the study area (Eberhardt and Thomas 1991).

The study design required sampling surveys in a particular habitat to be conducted over the shortest period possible, in order to maintain confidence in the assumption that the sampling survey was as close as practical to an instantaneous assessment of the complete habitat for that survey. All sampling surveys for this research were conducted underwater by divers using scuba. The author conducted 172 diving surveys for this Dissertation research during 1993 to 1995, and 121 diving surveys participating in support research projects in 1991 and 1992 (West et al. 1994, West et al. 1995, Doty et al 1995). All diving operations were required to follow safety protocols for non-decompression diving time limits (Anon. 1993). The limitations on the sampling period and the bottom time allowed for a survey, and the surface interval required before another survey dive could be made, imposed severe constraints on the amount of habitat that could be included in a given sampling survey. These time constraints were the practical factors controlling sample size determinations in this research.

### Spatial and Temporal Scale

The large sizes of BCAR, GIAR, EKM, MKM, and GIKM, and their continuity over time, enabled assessments of recruitment and survival of juvenile rockfishes on ecologically relevant spatial and temporal scales. The relevance of scale in conclusions reached in many marine fish ecological studies, has been demonstrated by the variability of results from surveys of recruitment of coral reef fishes which spanned spatial scales of meters to over 1,000 km, and temporal scales from days to almost a decade (Doherty 1987). Recruitment studies conducted at physical scales that are small relative to the space required for normal species interactions, abiotic processes, and other parameters affecting recruitment, are almost always relevant only at the scale of the particular study format (Doherty 1987, 1988). Similarly, recruitment studies conducted at temporal scales that are not appropriate to the longevity of the species, or the life history stage being studied, seldom include all of the ecological processes affecting recruitment (Jones 1990). Brock et al. (1979) noted that previous marine fish ecological studies had exaggerated the significance of variations in recruitment processes by choosing scales inappropriate to the issues addressed.

Ecological studies at restricted temporal and spatial scales tend to have better control over sources of ambient variation, but the results may not be relevant to the ecology of the species under study because the effects of the restrictions (i.e., the simplifications) on the systems are not considered (Ford 1995). Controlling natural variation narrows the applicability of the results because the study conditions do not resemble the real ecosystem (Eberhardt and Thomas 1991). In comparison, "natural level" studies provide valuable opportunities to assess large-scale ecosystem dynamics under open, or partially open, systems conditions; however, the formats of these studies rarely satisfy the accepted protocols of analytical experimental designs (Doherty 1991). While these studies allow contrasts over time, their large-scales limit or eliminate replication of the study areas, or development of control areas (Ford 1995).

BCAR and GIAR were located within the same general region of northcentral Puget Sound, but they were not replicate habitats due to several differences in their basic designs (Figures 2.4 and 2.5), their separation by 27.8 km, and their having only similar environmental parameters. Also, there were unknown annual variations in the numbers and species of the juvenile rockfish recruits available in each of the artificial reef areas, which precluded direct comparisons between BCAR and GIAR. Direct determination of enhanced juvenile rockfish recruitment and survival in these artificial reef areas, in response to the addition of substrates with abundant refuge habitats, would have required either (1) long-term comparative assessments of recruitment before, and after, the addition of the refuge habitat substrates, or (2) replication of the artificial reefs with, and without, the refuge habitat substrates. Neither of these approaches were possible because juvenile rockfish recruitment studies were not conducted prior to construction of the refuge habitat substrates, and replication of these large scale artificial reefs was not ecologically, physically, or economically feasible. The design of refuge habitat substrates in ARH and IRH pairs allowed comparisons of recruitment of juvenile rockfishes within BCAR and GIAR, when directly adjacent to, and isolated from, populations of potentially competitive or predatory sub-adult and adult rockfishes, as well as other piscivorous fishes.

### Identification and Enumeration of *Sebastes*

Juvenile copper rockfish, quillback rockfish, and brown rockfish are common on BCAR, GIAR, EKM, MKM, and GIKM, and juvenile Puget Sound rockfish (*S. emphaeus*) are also common on BCAR (Washington Department of Fish and Wildlife, unpublished). Visual identification of these juvenile rockfishes during underwater surveys was accomplished by developing a set of distinguishing gross morphological features and coloration patterns for recognizing each species (Anderson 1983, Stein and Hassler 1989, Moreland and Reilly 1991, Carr 1991), and verifying the accuracy of this method through meristics (Chen 1986, Matarese et al. 1989) and aquarium grow-out studies at the Seattle Public Aquarium, Seattle, Washington (see Chapter 1). Brown rockfish juveniles, and "larger" Puget Sound rockfish juveniles, were readily identified by distinctive coloration patterns. Early settlement-stage Puget Sound rockfish, with less distinctive coloration patterns, were present only during the early spring recruitment period, and thus were temporally separated from the other rockfishes which recruited in the fall. Copper rockfish and quillback rockfish juveniles were more difficult to distinguish, especially at sizes <30 mm TL; however, copper rockfish juveniles had five distinct red-brown vertical bands of pigment alternating with translucent areas, and quillback juveniles were more evenly pigmented, with a band of more intense pigment under the soft dorsal fin, and often had speckled coloration on the lower body (Moreland and Reilly 1991). These coloration patterns became more distinct at sizes approximately >50 mm TL. These characteristics were verified as sufficiently accurate (estimated 95% accurate in several unstructured tests) for identifying juvenile copper rockfish and quillback rockfish during underwater surveys. Pigmentation patterns were more distinct in live juvenile rockfishes *in situ* than in dead or preserved specimens, enabling more accurate identification with experienced observations (Carr 1991) than has been reported in the literature (Mathews 1988, 1990, West et al. 1994, Doty et al. 1995, West et al 1995).

Visual identification of sub-adult and adult copper rockfish and quillback rockfish during underwater surveys followed the characteristic morphology and coloration patterns of each species given in numerous species descriptions (e.g., Hart 1980) and pictorial references (e.g., Haw and Buckley 1971).

*Sebastes* encountered during underwater surveys were tallied by 1 cm length intervals on waterproof survey forms, based on visual estimations of total lengths that were aided by a 0 to 20 cm scale on the survey form. Lengths were rounded up to the whole cm interval to facilitate rapid recording of the counts, unless more precise length estimates were possible through comparisons with the scale. Lengths were recorded for each juvenile copper rockfish and quillback rockfish encountered during the surveys. Sub-adult and adult rockfishes were often grouped into convenient length categories spanning several cm intervals (e.g., 15-18 cm TL) to decrease the amount of survey time in any given area. All rockfishes larger than 20 cm TL were recorded as >20 cm TL.

Length intervals used to temporally separate juvenile rockfishes from rockfishes from previous cohorts, were estimated using the lengths and growth rate of the 1990 cohort juvenile rockfishes captured in central Puget Sound for the study to develop micro-tagging techniques (Table 1.1, see Chapter 1; Buckley et al. 1994). Previous studies had defined rockfishes ≤ 80 mm TL (Mathews 1988, 1990, West et al. 1994), and rockfishes ≤ 90 mm TL (West et al. 1995), as juveniles during the first cohort-year. The group of 1990 cohort juvenile rockfishes (a mixture of 93.3% quillback, copper, brown rockfish, and 6.7% Puget Sound rockfish) captured on November 1 (i.e., cohort-year day - c-y d 124[11] ), ranged from 47 to 94 mm TL (n = 62, average ± standard deviation - SD, 63.6 ± 11.1 mm TL), and had an average growth rate of 0.15 mm $d^{-1}$ over 310 d, under aquarium conditions. The 95% Confidence Interval (CI) for the average length for this group of juvenile rockfishes on c-y d 124 is given by (after Zar 1984):

$$X \pm t_{\alpha(2),\, v}\, s_x$$

where:

$X$ = average total length in mm

$t_{\alpha(2),\, v}$ = t distribution for $\alpha = 0.05$, $v = n - 1 = 61$ degrees of freedom

$s_x$ = standard error of the average total length = SD $n^{-1/2}$

With $t_{0.05\,(2),\,61} \approx 2.000$, the 95% CI for the average length is 63.6 ± 15.7 mm TL, which gives an upper confidence limit of 79.3 mm TL on c-y d 124. At the average growth rate of 0.15 mm $d^{-1}$, by c-y d 210 the 95% upper confidence limit for this average length would have increased to 90.9 mm TL; by the end of the first cohort-year ( c-y d 365) the 95% upper confidence limit for this average length would have increased to 115.5 mm TL. This indicates that the maximum

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[11] The cohort-year starts on July 1 and ends on June 30; November 1 is cohort-year day 124; see Data Analyses Methods, Table 2.3.

lengths of ≤ 80 and ≤ 90 mm TL used in previous studies for juvenile rockfishes during the first cohort-year, were too small later in the cohort-year.

To avoid mixing juvenile rockfishes from different cohorts, early in the cohort-year, temporally increasing length intervals were established to identify juveniles for individual length estimates during the surveys; ≤ 80 mm TL up to c-y d 75, ≤ 100 mm TL for c-y d 75-100, ≤ 110 mm TL for c-y d 101-200, and ≤ 120 mm TL for c-y d 201-365. These length intervals were designed to be liberal so that they would include all possible juvenile rockfishes; the length intervals would be refined as the study progressed, and additional length frequency samples of juvenile rockfishes became available.

Counts of all rockfishes were recorded for a given area of the habitat covered by a survey. The area of habitat included in each survey varied by survey method and habitat type. For quantified surveys, all counts were converted to density estimates of either numbers per length interval $m^{-2}$, or numbers per life stage (i.e., juvenile, or sub-adult and adult) $m^{-2}$, to standardize enumerations for comparisons and contrasts between and among habitat types.

### Quadrate Surveys

Underwater surveys of fixed quadrates were used to enumerate the 1994 cohorts of copper rockfish and quillback rockfish in the 1994 and 1995 surveys of BCAR and GIAR. Quadrates were systematically located at 4 m intervals, and stratified by alternating on either side of the center line of the strips of refuge habitat substrate on BCAR and GIAR (Figures 2.4 and 2.5). Each quadrate covered 12 $m^2$ (3 m wide by 4 m long) and was oriented with the long axis parallel to the center line of the strip of refuge substrate. The positions of the quadrates were based on random selections of (1) the end of the strip of substrate to begin sequentially locating the quadrates, (2) the location of the first quadrate to either the right or left of the center line of the strip of substrate, and (3) the designation of first 4 m section of the strip of substrate as either a quadrate, or an interval before a quadrate. The quadrates were stratified by placing a 3 m by 4 m plastic pipe frame on the substrate, and the positions of the corners of the frame were marked with plastic pipe stakes driven into the substrate. Colored plastic tape was attached to the corner stakes to make the boundaries of the quadrate easily recognizable during the surveys. The approximately 6 m width of the strip of substrate, and the 3 m width of the plastic pipe frame, resulted in quadrates on either side of the center line of the substrate including both the central habitat of the refuge substrate and the edge habitat (i.e., the interface between the rock and the natural substrate). After each quadrate was marked, the frame was advanced 4 m and moved to the opposite side of the center line of the strip of substrate, to locate the next sequential quadrate

The refuge habitat substrates on BCAR and GIAR were stratified into ARH and IRH, and the strips of substrate at each artificial reef location were sub-stratified into perpendicular to the shoreline (BCAR - north, central, and south habitats; GIAR - east and west habitats) and parallel to the shoreline (BCAR and GIAR - base habitats), as these differences in orientation could affect recruitment and distributions of juvenile rockfishes. Under this sampling design, each sub-strata of refuge substrate contained 6 quadrates, or 72 $m^2$ of sampling area. The amount of the area of the ARH and IRH substrates at BCAR and GIAR covered by the 6 quadrates was approximately 20% in each sub-strata (Appendix I).

Surveys for 1994 cohort juvenile rockfishes on the original artificial reef habitat on BCAR were conducted using 4 fixed 12 $m^2$ quadrates, which were systematically established at 4 m intervals on the original reef substrate parallel to the ARH base habitat. These quadrates were positioned on the large rock substrate by proceeding on a northerly bearing from a randomly selected point on the substrate, and fixed by establishing markers at the corners of a 3 m wide by 4 m long rectangle. Similar surveys on the original artificial reef habitat on GIAR could not be conducted using fixed quadrates, due to the cave-like, high profile substrate of the artificial reef adjacent to the ARH base habitat. These surveys were conducted using a fixed 3 m wide strip transect, divided into 4 m segments. The amount of area surveyed on both the BCAR and GIAR original artificial reef habitats was allocated based on the amount of no decompression scuba diving bottom time remaining after surveying the quadrates on the ARH base habitats.

The distributions of the quadrates, and the stratifications of the refuge substrates, were based on the assumption that the ARH and IRH substrates on BCAR and GIAR were similar, especially in the widths and heights of the strips of the refuge substrates. However, in the fall of 1994 it was noted at BCAR that unusual movements of the sloping sand substrates, which had provided stable bases for three years (1991-1994) for the north, central, and south habitats of the ARH and IRH, were rapidly filling in the crevices in the rocky substrates, burying the rocks, and smothering the attached macrophytes. This severely restricted the refuge potential of these substrates for juvenile rockfishes, and the refuge potential decreased over time with increasing accumulations of sand. These refuge substrates on BCAR were removed from the sampling design with the October 29, 1994 surveys, and only the base habitats of the ARH and IRH, which were at deeper depths and essentially unaffected by the movements of the sand substrate, were regularly included in the remainder of the sampling surveys.

Protocols were established for enumeration of the copper rockfish and quillback rockfish found in each quadrate, which reduced the potential for repeat counts of the same fish. These protocols were based on both the normal behavior of the rockfishes in relation to the diver (the rockfishes often did not move away unless they were within 50 cm of the diver), and the most efficient method for surveying all of the quadrates on either the ARH or IRH in a single dive. Repeat counts were not a serious potential source of error for enumeration of juvenile rockfishes, which were highly associated with the substrate and moved into the crevices in the substrate if disturbed by the diver, rather than swim away. The behavior of the sub-adult and adult rockfishes differed somewhat in that, if they were disturbed by the diver, they would move away from the diver, usually laterally for short distances, and then resume their previous orientation to the substrate behind the diver.

The most efficient method for surveying the quadrates was to start the survey at the end of the strip of refuge substrate, and swim the length of the substrate surveying each quadrate in sequence. The surveys at BCAR and GIAR were always conducted when underwater visibility conditions were >4 m, so the entire quadrate could be viewed by the diver conducting the survey. The diver would first enumerate the easily visible sub-adult and adult rockfishes in the quadrate, while outside the quadrate at a 3 m wide end. The diver would then move through the quadrate, along the 4 m length, moving from side to side, enumerating the juvenile rockfishes that were above the substrate and searching in the crevice habitats for additional rockfishes. When a quadrate survey was completed, the diver would move diagonally across the strip of substrate to the 3 m end of the next quadrate in sequence. This method of reduced diver movements while surveying a quadrate, followed by direct movement to the next quadrate, reduced the potential for "herding" any rockfishes into the next quadrates, and thereby confounding the accuracy of the enumerations.

### Strip Transect Surveys

Underwater visual strip transects (*sensu* Brock 1954) were used to enumerate copper rockfish and quillback rockfish in all surveys of sand, eelgrass, bull kelp frond (i.e., surface), and understory macrophyte (i.e., benthic) habitats, and in some surveys of the artificial reef habitats. When conducting a strip transect survey, the diver would move slowly along a straight course, enumerating the rockfishes encountered within the prescribed width of the transect, searching as far ahead as visibility allowed for accurate counts. To quantify the surveys, the lengths of the strip transects were determined by paying out a metric tape contained on a reel, from the beginning to the end of the transect. The widths of the strip transect varied from 1 to 3 m depending upon the effects of habitat complexity on the efficiency of enumerating juvenile rockfishes; strip transects in dense macrophytes which obscured visibility were usually 1 m wide, while strip transects open sand habitat were 3 m wide. The height of the strip transects was 1 m above the substrate, or 1 m below the surface for transects in bull kelp fronds. The rockfishes encountered along the strip transects were almost always strongly associated with a particular structure in the habitat and did not move away until approached closely (usually at distance of <50 cm), reducing the potential for repeat enumeration of the same fish. Although transect counts were made in three dimensions, virtually all rockfishes, especially the juveniles, were always within <0.5 m of the substrate, or the surface, so transect areas, and not volumes, were used for density estimates.

Strip transects conducted in eelgrass, bull kelp frond, and benthic macrophyte habitats included physically disturbing the vegetation along the length of the transect to cause the juvenile rockfishes to move out of the refuge habitat and into the open water. Transects in rocky-reef habitats with abundant crevices for refuge, especially on artificial reefs, were conducted using underwater lights to aid visual searches into the crevices for juvenile rockfishes; the rock substrate was not disturbed (i.e., the rocks were not moved).

Some transects, or searches, were qualitative to determine the presence or absence of juvenile copper rockfish and quillback rockfish in particular habitats. The widths of these surveys varied, and they were often not continuous. Qualitative surveys were usually used to rapidly search large areas of habitat to document the timing of the first substrate associated recruitment of juvenile rockfishes. When juvenile rockfishes were noted, subsequent surveys were quantitative strip transects.

Strip transects in sand, eelgrass, bull kelp frond (i.e., surface), and understory macrophyte (i.e., benthic) habitats, were started at random locations within the habitat, and usually extended at least 50 m, or to the edge of the habitat (except in sand habitat) following a compass bearing. The strip transects usually crossed all depth contours of these habitats in a zigzag pattern. The number of strip transects conducted in a particular habitat during a survey, were based on the amount of diving time available for the underwater survey.

### Pilot Study Manipulation of Natural Substrate

In the summer of 1993, the natural substrate of the bull kelp bed at EKM was manipulated to create two patch reef areas. This study explored the effect of increased crevice or refuge habitat on the temporal distribution and number of juvenile rockfishes in this shallow nearshore habitat. The normal response of juvenile rockfishes was to vacate this nearshore, shallow water habitat in December-January with the loss of the biogenic complexity of the macrophyte habitat (Doty et al. 1995).

The two patch reefs were constructed along the -7 m MLLW depth contour by digging stones out of the substrate and piling them in areas approximately 30 m apart. The patch reefs were located in the offshore one third of the bull kelp bed area, to determine if juvenile rockfishes would use the crevice habitats instead of migrating offshore with the detached, drifting benthic macrophytes. The north patch reef was 5m by 5 m by 2 m high, and the south patch reef was 6 m by 5 m by 2.5 m high; both patch reefs contained abundant crevice habitats.

### Correlation Study and Substrate Rugosity Measurements

The complexity, or rugosity, of the ARH and IRH substrates was expected to be a major habitat parameter affecting the substrate associated recruitment and survival of juvenile copper rockfish and quillback rockfish on BCAR and GIAR. Substrate surface area is a significant functional ecological parameter affecting recruitment in marine ecosystems (Dahl 1973, Shulman 1984, 1985, Behrents 1987, Hixon and Beets 1993). Habitat rugosity is the complexity of the benthic habitat created by the type of substrate, and interstices in the substrate, or, similarly, the spatial arrangement and diversity of the types of surfaces of the substrate (McCormick 1994). The rugosity of the crevice substrates of the ARH and IRH resulted from the multiple layers of small angular rocks forming the low profile substrates. The number and refuge potential (i.e., the size and depth) of the crevices in these substrates was likely related to the number of rocks and the layers of rocks within a given area. However, determination of these two parameters to quantify the rugosity of the substrates would have involved disruptive and destructive sampling, that is, moving the rocks forming the ARH and IRH substrates.

Determination of the rugosity of the ARH and IRH substrates within the areas sampled for substrate associated recruitment of juvenile rockfishes (i.e., within the quadrate survey areas) required quantified measurements that would not alter the substrate configuration. Several non-destructive methods have been used to physically measure and quantify the rugosity of temperate and tropical reef substrates, but most of these methods have ranges of ambiguity in their applications that could affect the resulting measurements (e.g., the ratio of the length of chain contoured over the substrate, to the linear distance between the chain's ends - Luckhurst and Luckhurst 1978; Loi 1981). To quantify the rugosity of the ARH and IRH substrates, a 1 m long profile gauge, with 11 vertical measuring rods spaced at 10 cm intervals, was used to measured changes in substrate surface topography along transect lines in the quadrate survey areas (Figure 2.6; McCormick 1994). The profile gauge provided standardized measurements of the substrate rugosity.

The rugosities of the ARH and IRH quadrate survey areas on BCAR and GIAR were quantified as the summation of the squared differences between the heights (in cm) of consecutive measuring rods above a constant horizontal

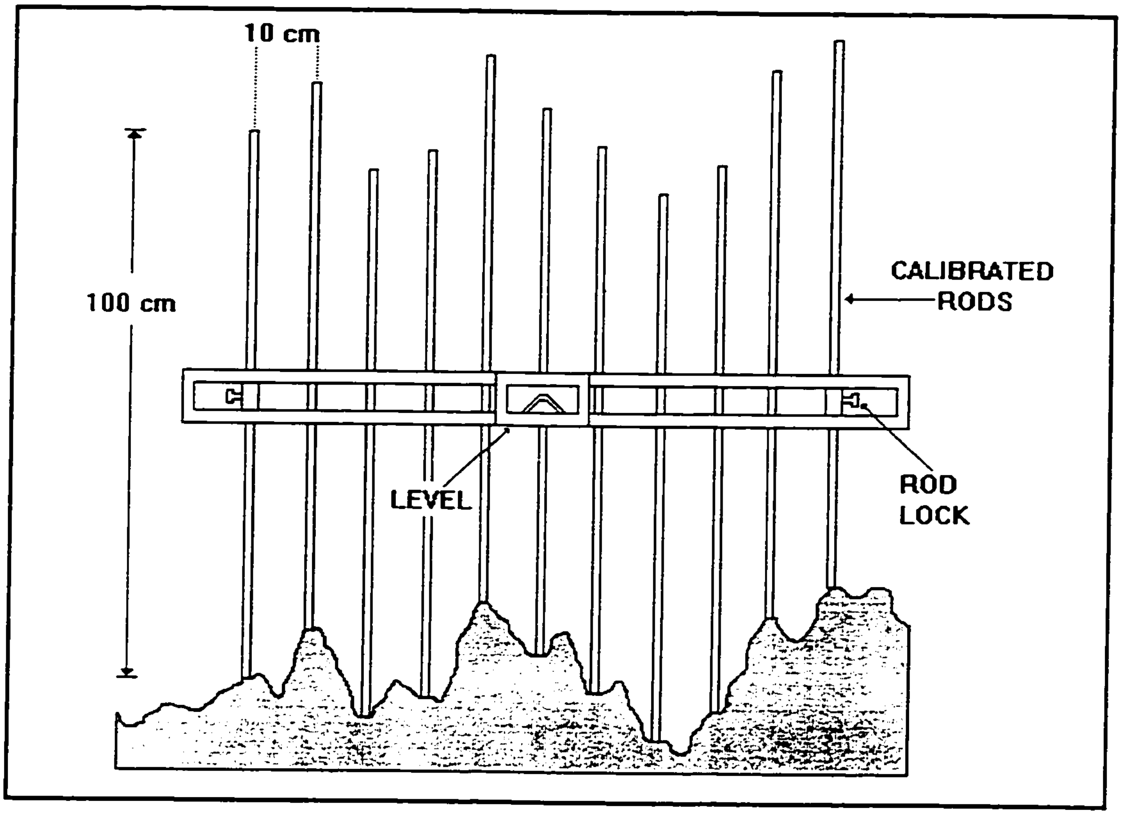


Figure 2.6. Substrate profile gauge used for rugosity measurements.

reference point (after McCormick 1994). Rugosity measurements were taken along three sequential transects, at 1 m intervals across the 3 m width of the quadrates. The location of these transects was determined by placing a leaded line across the quadrate at measured distances between the corner stakes marking the 4 m length of the quadrates. The rugosity gauge was leveled and deployed end-on-end three times along the transect line to complete the 3 m transect, giving 31 measures of substrate height.

A *post priori* study was conducted on the IRH of BCAR to determine the degree of correlation between the rugosity gauge quantification of substrate complexity, and the numbers of rocks and the layers of rocks, determined by destructive sampling, along common 3 m long transect lines. A sample of 11 transect lines was randomly selected from 30 rugosity transects of the six quadrate survey areas, which had been stratified by the cumulative rugosity values of the transects. These rugosity values (in $cm^2$) ranged from 449 to 5,619, and were stratified as <500, 500 to 1,500, >1500 to 2,500, >2,500 to 3,500, >3,500 to 4,500, and >4,500. The numbers and layers of rocks along each transect line were systematically sampled by placing 0.3 $m^2$ quadrates at the 0, 1, 2, and 3 m locations on each 3 m transect line. The rocks >9 cm in diameter that were visible on the substrate surface, which were partially or completely within the quadrate, were counted, and then the rocks in the quadrate area were removed to determine the number of layers of rock that extended above the sand substrate.

The rugosity values of the sampled transects were significantly positively correlated with the layers of rocks on the transects (CC; $r = 0.90$, $p < 0.001$), and with the numbers of rocks (CC; $r = 0.71$, $p < 0.001$). These high correlation values were supported by the intuitive positive relationships between the number of rocks and the layers of rocks forming the substrates, and the crevices in the substrates. The rugosity values were used as quantified estimates of the refuge habitat potential (i.e., the numbers of crevice habitats) of the ARH and IRH substrates.

### Tagging of Juvenile *Sebastes* and Tag Recovery Surveys

The development of the techniques used in this research to apply internal micro-tags to juvenile *Sebastes* have been discussed in Chapter 1. The Visible Implant Fluorescent (VIF) red filament tag was used as the primary method to batch mark experimental groups of juvenile rockfishes. This type of tag was ideally suited for monitoring both short-term and long-term movements and migrations of groups of juvenile rockfishes, as the tags it could be "recovered" without physical recapture of the fish and disruption of normal behavior and distributions. The use of one color of VIF tag implanted in the two anatomical locations that were tested (i.e., nape and mid-dorsal), limited the number of batch tagged groups that could be identified, but these limited variations were sufficient for this research.

The main problem encountered during operations to tag juvenile *Sebastes* in this research, was the difficulty in capturing the fish from the physically complex and rugose habitats of the artificial reefs and the bull kelp and understory macrophyte habitats. Care was also taken to capture the juveniles rockfishes without causing injuries to the fish, which would have invalidated the assumption of high rates of survival after the tagging process. The method that proved most effective in capturing substrate associated juvenile rockfishes, was divers using two hand nets, and live buckets for holding the fish after capture. The hand nets had 30 cm diameter openings, with 30 cm deep bags of loosely woven 2 mm diameter dark red mesh. The live buckets were 15 l containers, with large, soft rubber flap valves in the lids for inserting the fish, and fine mesh plastic screen in the sides for water circulation. The net bag containing the fish was thrust through the flap valve in the live bucket, and the net inverted inside the bucket, releasing the fish.

Juvenile rockfishes were captured at depths between 4.5 and 9 m, placed in live buckets, and brought to the surface slowly to avoid embolisms. At the surface, the juveniles were held in darkened ice chests with fresh sea water to minimize stress, and removed in small numbers for anesthetizing with MS222 at a concentration of 0.05 g $l^{-1}$, measuring, and tagging. After tagging, the juveniles were allowed to recover from the anesthetic, placed in live buckets, and returned by divers to the depth and habitat where they were captured, and released. Divers monitored the reaction and condition of the juvenile rockfishes at release to determine if there were any immediate physical problems.

Juvenile rockfishes were vulnerable to capture early in the substrate association phase, when they were still in small schools and somewhat loosely associated with the benthic substrate. A "single stage" tagging and multiple stage recapture method was used for these tagging studies (Lebreton et al. 1992), where the capture and tagging was targeted during this short period of vulnerability, and tag recovery surveys for the movements, migrations, and survivals of groups of these juvenile rockfish were conducted during the first year of the substrate association phase.

Three groups of juvenile rockfishes were tagged and released in studies for this research. A tagging study was conducted at BCAR during the 1991 recruitment season (1) to confirm the ability to recover juvenile rockfishes with VIF tags during transect surveys on complex benthic substrates, (2) to test the association of the juvenile rockfishes with specific habitats during the early substrate association phase, and (3) to estimate the survival rate for the juvenile rockfishes in this habitat. In this study, a test release of three juvenile quillback rockfish, with VIF tags in the left mid-dorsal region, was made on the IRH central habitat on October 11, and a subsequent release of 53 similarly tagged juvenile quillback rockfish (two of the juveniles may have been copper rockfish) was made in the same habitat on October 25.

Tagging studies in natural habitats were conducted at GIKM during the 1992 recruitment season, and at EKM during the 1993 recruitment season. The study at GIKM was conducted to (1) monitor the habitat use and distributions of juvenile rockfishes in this natural habitat, and (2) determine if any juvenile rockfishes in this nearshore natural habitat migrated to the nearby offshore habitats of GIAR, after the seasonal loss of macrophytes. In this study, 247 juvenile rockfishes from the 1992 cohort (primarily quillback rockfish, with possibly some copper rockfish) were tagged with VIF tags in the left mid-dorsal region and released at GIKM during October 12 to 22. The study at EKM was conducted to (1) monitor temporal differences in habitat use and distributions of juvenile rockfishes in this natural habitat, and (2) determine if any juvenile rockfishes in this natural habitat utilized patch reefs of enhanced refuge habitat within EKM after the seasonal loss of macrophytes. In this study, 212 juvenile quillback rockfish from the 1993 cohort were tagged with VIF tags and released at EKM; 112 juveniles were tagged with VIF tags in the left mid-dorsal region and released on October 14, and 100 juveniles were tagged with VIF tags in the right nape and released on November 5.

On November 8, 13 juvenile quillback rockfish from the 1993 cohort were collected from MKM, tagged with VIF tags in the left mid-dorsal region, and placed in the public aquarium in Tacoma, to recheck the effects of the tagging procedures on long-term survival and tag retention rates.

### Identification and Enumeration of Macrophytes

Identification of the macrophytes on the substrates at BCAR, GIAR, EKM, MKM, and GIKM was limited to the macro-forms which provided biogenic habitat with abundant refuge potential for the juvenile copper rockfish and quillback rockfish. These were primarily the annual and perennial brown algae with long broad blades, and often long stipes (e.g., *Laminaria saccharina*, *Costaria costata*, *Agarum* sp., *Desmerestia* sp., *Nereocystis luetkeana*., etc.), which combined to from layers of vegetation over-covering the rock substrate. Other macrophytes were often grouped as unidentified brown algae, folious turf red algae, or green ulvoids. Identification of macrophytes to genus or species was based primarily on visual recognition underwater, with occasional collection of specimens to compare with taxonomic descriptions (e.g., Scagel 1972).

Enumeration of macrophytes, other than bull kelp, was by visual estimation of percent coverage of the benthic substrates by brown algae in defined survey areas (e.g., quadrate survey areas). This was the quickest quantification method for estimating the effects of macrophytes on the refuge habitat value of the substrates, and it was the least disruptive to the distributions of juvenile rockfishes in the survey areas. Visual estimation of percent cover is as reliable for quantifying gross habitat features as other more precise techniques (Meese and Tomich 1992), many of which are more disruptive (e.g., physical evaluations within quadrates; random point contact surveys - Loi 1981) or destructive (e.g., removal of organisms within quadrates) to the benthic habitat and associated fauna. Bull kelp was enumerated by counting the stipes in defined survey areas. In a specific situation in EKM when the understory macrophytes had become detached from the substrate and formed benthic drift algae, the thickness of the drift was directly measured along transect lines.

No attempt was made to conduct tests for correlations between macrophyte types, or percent coverage estimates, and the refuge habitat value of the substrates at BCAR, GIAR, EKM, MKM, or GIKM. The presence and abundance of juvenile rockfishes have been qualitatively related to macrophytes densities in Puget Sound habitats, and they have been shown to be positively correlated with the presence and abundance of macrophytes in other ecosystems (Haldorson and Richards 1987, Mathews 1988, Carr 1994a, 1994b, Doty et al. 1995, West et al. 1995).

### Allocation of Sampling Surveys

The sampling surveys on BCAR, GIAR, EKM, MKM, and GIKM were conducted almost exclusively during daylight hours, and during slack to moderate tidal flows. Although nocturnal and diurnal survey comparisons of the enumerations of the juvenile rockfishes would have been desirable in all habitats surveyed, especially in the rugose substrates of BCAR and GIAR, problems in several of the study areas prevented nocturnal surveys. GIAR and GIKM were located approximately 5 km from the nearest lighted reference locations that could be used as “line-ups” for night positioning, making the line-ups highly inaccurate. Also, surface buoys could not be maintained to mark the locations of the ARH and IRH at GIAR due to frequent vessel traffic. The vessel traffic also posed a danger to divers at night. BCAR was located close to shore with adequate lighted reference points and surface buoys for locating the study area at night, and there was minimal vessel traffic in the area. However, nocturnal surveys were terminated at BCAR after May 5, 1992, when urban violence at the boat launching location for this study area endangered divers returning from a night dive. EKM was close to shore and easily located at night, with safe diving conditions and night boat launching access. Minimal nocturnal surveys were conducted in this study area in 1994 and 1995.

To recover tagged juvenile rockfishes from the October 1991 tagging study at BCAR, a total of 10 surveys, six diurnal and four nocturnal, were conducted from December 13, 1991 (49 d after release of the tagged fish) to July 9, 1992 (258 d post tag release). To recover tagged juvenile rockfishes from the October 1992 tagging study at GIKM, a total of four surveys were conducted from November 10, 1992 (19 d post tag release) to December 15, 1993 (54 d post tag release). Surveys to recover tagged juvenile rockfishes from the GIKM tagging study were also conducted at 104 d post tag release on the ARH, and at 112d post tag release on the IRH, of GIAR, the closest artificial reef habitat to GIKM. The 1993 tagging study at EKM involved two groups of quillback rockfish with tags in different anatomical locations. A total of 14 tag recovery surveys, five nocturnal and 9 diurnal, were conducted at EKM, from October 24, 1993 (10 d after the release of the first group), to February 2, 1994 (111 d and 89 d after the release of the first and second group, respectively).

EKM and MKM, and adjacent eelgrass habitats, and sand and eelgrass habitats adjacent to BCAR, were surveyed extensively by strip transects in July, August, and September 1994 to document the spatial and temporal distributions of the first substrate associated recruitment of juvenile rockfishes from the 1994 cohort in these habitats. Surveys on the ARH and IRH at GIAR to enumerate juvenile rockfishes included six complete sets of quadrate surveys on the east and base habitats, from September 1994 to June 1995, to assess the recruitment of the 1994 cohort. Surveys on the ARH and IRH at BCAR to enumerate juvenile rockfishes included the north, central, south and base habitats from August to October 1994, when surveys of the north, central and south habitats were eliminated due to accumulations of sand (see Quadrate Surveys); five complete sets of quadrate surveys on the base habitats were conducted from October 1994 to May 1995 to assess the recruitment of 1994 cohort juveniles.

### Data Analysis Methods

The estimated densities over time of cohorts of juvenile copper rockfish and quillback rockfish at BCAR, GIAR, EKM, MKM, and GIKM, and the recoveries of VIF tagged juvenile rockfishes in these habitats, were the primary statistics used to determine the spatial and temporal elements of substrate associated recruitment of the juveniles, as well as the subsequent survivals and movements of the juveniles, during the first year of substrate association. Juvenile copper rockfish and quillback rockfish have not been documented as settling prior to July 1 in Puget Sound habitats (see Juvenile *Sebastes* Recruitment Studies in Puget Sound, and Spatial and Temporal Parameters and Recruitment Pathways). To facilitate temporal comparisons between cohorts, time was measured on a scale of cohort-year days (c-y d) for each cohort (Table 2.2), which started on July 1 of the settlement year, and ended on June 30 of the following year.

Table 2.2. Cohort-year days for substrate associated recruitment of juvenile quillback rockfish and copper rockfish during the first cohort-year.

| | 1991 | 1992-1994 |
|---|---|---|
| | c-y d[1] | c-y d[1] |
| July 1 | 1 | 1 |
| July 15 | 15 | 15 |
| July 31 | 31 | 31 |
| Aug. 1 | 32 | 32 |
| Aug. 15 | 46 | 46 |
| Aug. 31 | 62 | 62 |
| Sep. 1 | 63 | 63 |
| Sep. 15 | 77 | 77 |
| Sep. 30 | 92 | 92 |
| Oct. 1 | 93 | 93 |
| Oct. 15 | 107 | 107 |
| Oct. 31 | 123 | 123 |
| Nov. 1 | 124 | 124 |
| Nov. 15 | 138 | 138 |
| Nov. 30 | 153 | 153 |
| Dec. 1 | 154 | 154 |
| Dec. 15 | 168 | 168 |
| Dec. 31 | 184 | 184 |

| | 1992 | 1993-1995 |
|---|---|---|
| | c-y d[1] | c-y d[1] |
| Jan. 1 | 185 | 185 |
| Jan. 15 | 199 | 199 |
| Jan. 31 | 215 | 215 |
| Feb. 1 | 216 | 216 |
| Feb. 15 | 230 | 230 |
| Feb. 28 | 243 | 243 |
| Feb. 29 | 244 | |
| Mar. 1 | 245 | 244 |
| Mar. 15 | 259 | 258 |
| Mar. 31 | 275 | 274 |
| April 1 | 276 | 275 |
| April 15 | 290 | 289 |
| April 30 | 305 | 304 |
| May 1 | 306 | 305 |
| May 15 | 320 | 319 |
| May 31 | 336 | 335 |
| June 1 | 337 | 336 |
| June 15 | 351 | 350 |
| June 30 | 366 | 365 |

[1] c-y d = cohort-year day.

Sampling data were analyzed using statistical and graphics procedures in Excel 5.0 (Microsoft 1994), Quattro Pro 1.0 (Borland 1992), SPSS 6.1 (Norusis 1993), and Paintbrush 4.0 (Microsoft 1989). Data in percentages were arcsine transformed (Zar 1984) to change binomial distributions to (nearly) normal distributions. Lognormally distributed data, or data where the error variances increased with the mean, were appropriately log-transformed (Zar 1984). Data distributions were estimated using the coefficient of dispersion (CD; Sokal and Rohlf 1981). Data normality was determined visually using the normal probability plot and the detrended normal plot, and statistically using the Lilliefors Kolmogorov-Smirnov test (L K-S test; Zar 1984, Norusis 1993). Data from normal bivariate populations were tested for relationships using correlation coefficients (CC; Zar 1984, Neter et al. 1990, Norusis 1993). Equality of sample variances was tested using the F-test (Zar 1984) and the Levene test (L test; Snedecor and Cochran 1980). Equality of sample means was tested using Analysis of Variance (ANOVA), the t-test, and the paired t-test (Zar 1984). Multiple comparisons of means were tested using the Tukey Honest Significant Difference test (Tukey-HSD test; Zar 1984, Norusis 1993).

The relationships between variables were tested using linear regressions procedures (Neter et al. 1990). Possible interaction effects between independent variables in regression models were assessed graphically, using visual interpretations of the patterns of residuals from first order models using the variables, plotted against the possible interaction terms (Neter et al. 1990). Multicollinearities of independent variables in regression models were determined using the values of the tolerance limits and variance inflation factors for the variables, and by the proportions of the variances of the regression coefficients of the variables associated with eigenvalues, when the varaibles were included in the regression equations (Neter et al. 1990, Norusis 1993). The most appropriate linear regression models to describe relationships between variables were constructed using the all-possible-regressions algorithm, and graphical assessments of the adjusted coefficients of determination ($R^2_a$) for each regression model (Neter et al. 1990, Norusis 1993). The significances of the final regression models were tested using Analysis of Variance (Zar 1984, Neter et al. 1990, Norusis 1993).

Survival rate estimates for groups of juvenile *Sebastes* that were identified with VIF tags were determined using the model (after Ricker 1978):

$$N_t / N_0 = e^{-Zt}$$

where:

$N_t$ = number of tagged fish present at time t
$N_0$ = number of tagged fish released
e = 2.71828 (a constant)
Z = instantaneous rate of loss (i.e., natural mortality and emigration)
t = time, in days after release of the tagged fish.

This model assumed a closed population, that is, the population of juvenile rockfishes at $t_0$ was the same as at $t_i$. Estimates of the instantaneous rate of loss for groups of VIF tagged juvenile *Sebastes* possibly included emigration in addition to natural mortality. Estimates of the rate of survival (S) are obtained from Z in the relationship (from Ricker 1978):

$$S = e^{-Z}$$

Models for habitat use were developed for groups of substrate associated juvenile *Sebastes* on BCAR and GIAR, using the following linear model, with six possible independent variables to include the effects of various physical and biological parameters on the selection and use of habitats:

$$Y_{hijklmn} = \mu + \alpha_h + \beta_i + \gamma_j + \varphi_k + \lambda_l + \theta_m + \text{[interactions]} + \varepsilon_{hijklmn}$$

where:

Y = the density of juvenile *Sebastes*

$\mu$ = overall mean

$\alpha$ = refuge substrate location affect

$\beta$ = benthic macrophyte habitat affect

$\gamma$ = refuge habitat depth affect

$\varphi$ = bull kelp habitat affect

$\lambda$ = previous cohorts of *Sebastes* affect

$\theta$ = refuge substrate rugosity affect

[interactions] = terms for interactions between $\alpha$, $\beta$, $\gamma$, $\varphi$, $\lambda$, and $\theta$

$\varepsilon$ = error

h = location of the refuge substrate in either the ARH or IRH

i = coverage of the benthic macrophyte habitat in the survey quadrates

j = depth of the refuge substrate survey quadrates

k = number of bull kelp plants in the survey quadrates

l = density of *Sebastes* from previous years cohorts in the survey quadrates

m= rugosity value of the substrate, or coverage by rock substrate, in the survey quadrates (see Rugosity of Artificial Reef Habitats)

n = number of quadrates surveyed (i.e., replicates).

The validity of the habitat use models were determined through Analysis of Variance.

## RESULTS

### 1991 Tagging on Boeing Creek Artificial Reef

The three VIF tagged, 1991 cohort quillback rockfish (55, 57, and 63 mm TL) released on October 11 on the central habitat of the IRH, were part of the 26 juvenile rockfishes surveyed on this habitat on that date (Table 2.3). One of these tagged fish was visually recovered, using a UV-A underwater light, in the 23 juveniles surveyed on the IRH central habitat at 11 d after tagging. The VIF tag was easily fluoresced from approximately 1 m distance, and was not visually ambiguous, verifying that the small, internal VIF tags (1 mm long x 0.25 mm in diameter) could be recovered *in situ* on complex benthic substrates.

The 53 VIF tagged, 1991 cohort juvenile rockfishes released on October 25 on the central habitat of the IRH, were collected during searches of the full length (approximately 288 $m^2$ ) of this habitat. These juveniles were identified as quillback rockfish, but possibly included two copper rockfish due to minor visual identification questions. Although none of the three similarly tagged rockfish released 14 d earlier were recovered in this sample, it was assumed for subsequent surveys that the total number of tagged fish on the central habitat was 56, and that 0 d for the total tag release could be considered as October 25 (c-y d 117; Table 2.3). The disturbance on the substrate caused by the collection of juvenile rockfishes with hand nets (see Tagging of Juvenile *Sebastes* and Tag Recovery Surveys) often resulted in some juveniles taking refuge in crevices in the substrate, and these juveniles could have been missed and not included in the collection. The 53 tagged rockfish ranged from 40 to 73 mm TL, (average length ± standard deviation; 61.3 ± 7.4 mm TL; Figure 2.7), which encompassed the sizes of the three tagged rockfish released on October 11.

Table 2.3. Release and recovery of 1991 cohort juvenile quillback rockfish tagged with Visible Implant Fluorescent filament tags on Boeing Creek Artificial Reef IRH central habitat.

| | | | | Survey[3] | | | | | | Density[5] | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Time | c-y d[1] | Tag d[2] | Area | n | Tag Rel. | Tag Rec. | % Tag | % Tag Rel.[4] | Tag | n |
| 10/11/91 | Day | 103 | 0 | 244 | 26 | 3 | | | | | 0.167 |
| 10/22/91 | Day | 114 | 11 | 150 | 23 | | 1 | 4.4 | 33.3 | 0.007 | 0.153 |
| 10/25/91 | Day | 117 | 0 | 288* | 53 | 56 | | | | | 0.184 |
| 12/13/91 | Day | 166 | 49 | 240 | 9 | | 3 | 33.3 | 5.4 | 0.013 | 0.038 |
| 12/17/91 | Night | 170 | 53 | 200 | 25 | | 7 | 28 | 12.3 | 0.035 | 0.125 |
| 2/5/92 | Day | 220 | 103 | 200 | 9 | | 1 | 11.1 | 1.8 | 0.005 | 0.041 |
| 3/19/92 | Day | 263 | 146 | 262 | 7 | | 0 | 0 | 0 | 0 | 0.027 |
| 4/20/92 | Day | 295 | 178 | 180 | 4 | | 0 | 0 | 0 | 0 | 0.022 |
| 4/20/92 | Night | 295 | 178 | 270 | 33 | | 11 | 33.3 | 19.6 | 0.041 | 0.122 |
| 5/5/92 | Night | 310 | 193 | 255 | 26 | | 12 | 46.2 | 21.4 | 0.047 | 0.102 |
| 5/20/92 | Day | 325 | 208 | 190* | 33 | | 7 | 26.9 | 12.5 | 0.037 | 0.174 |
| 6/17/92 | Day | 353 | 236 | 190* | 35 | | 2 | 5.7 | 3.6 | 0.011 | 0.184 |
| 7/9/92 | Day | 374 | 258 | 190* | 37 | | 4 | 10.8 | 7.1 | 0.021 | 0.195 |

1] c-y d = cohort-year day; see Table 2.3.

2] Days post-tagging and release.

3] Area surveyed in $m^2$. * denotes collections of juvenile rockfish; number of tagged fish released (Tag Rel.) and recovered (Tag Rec.); percentage of tagged fish (% Tag) in survey.

4] Percentage of the total tagged fish released that were recovered in the survey.

5] Tagged (Tag) and total (n) fish $m^{-2}$ in the survey; densities from collections probably biased low.

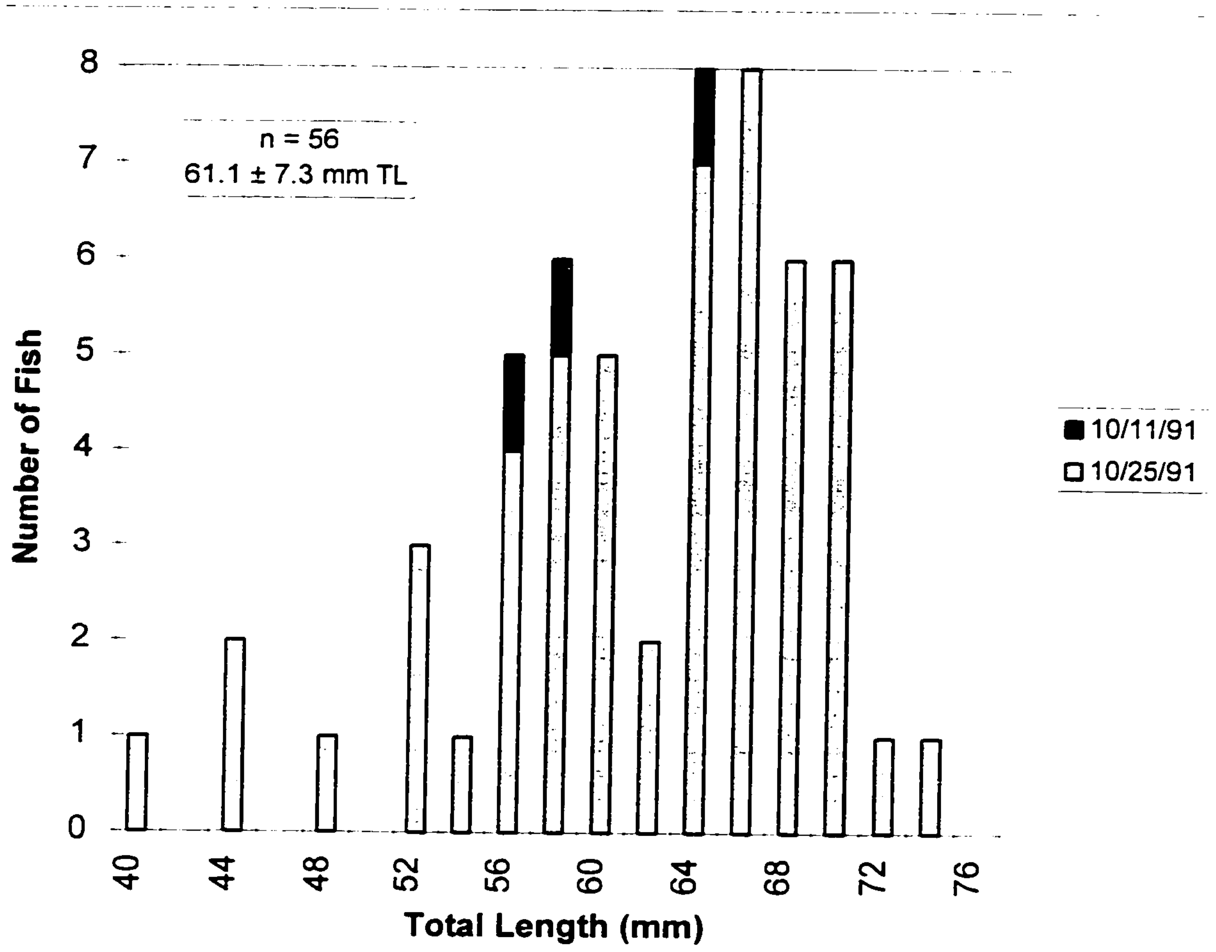


Figure 2.7. Length frequency distribution of 1991 cohort juvenile rockfish tagged on Boeing Creek Artificial Reef IRH central habitat.

Visual surveys of the IRH north, central, south, and base habitats, up to 193 d after the release of the tagged juveniles, recovered tagged fish only on the central habitat (Table 2.3; Appendix II), indicating minimal emigration of tagged juveniles from the release habitat. The densities of tagged juvenile rockfish in the diurnal surveys of the central habitat decreased to 0 by 146 d, which corresponded to c-y d 263 (Table 2.3; Figure 2.8), and remained at 0 for the diurnal survey at 178 d. However, the nocturnal surveys of the central habitat at 178 d and 193 d found the highest densities of tagged juvenile rockfish recorded for this tag release, as well as increased densities of non-tagged juveniles. This was clear indication that the juvenile rockfish had not emigrated, but were just not available to diurnal visual surveys during this period. This temporally variable detectability and nocturnal activity pattern of juvenile rockfish was common to both tagged and non-tagged juveniles, as paired diurnal/nocturnal surveys found that nocturnal surveys had higher densities of both tagged (paired t-test; $|t| = 4.400$, $p = 0.048$) and non-tagged (paired t-test; $|t| = 13.071$, $p = 0.006$) juvenile rockfish (Table 2.3).

The pattern of temporally decreasing and then increasing densities of juvenile quillback rockfish and copper rockfish was found in surveys on all habitats of the IRH (Figure 2.9). The percent of tagged juvenile rockfishes in the survey samples of the IRH central habitat demonstrated this same pattern, decreasing to 28% by the nocturnal survey at 53 d after release (c-y d 170), and 0% by 146 d (c-y d 263; Figure 2.10). The percent of tagged rockfishes in the surveys increased to 46.2% by the nocturnal survey at 193 d after release (c-y d 310). The percent of the survey samples that were tagged juvenile rockfishes could have been influenced by undetected immigration and emigration on the IRH

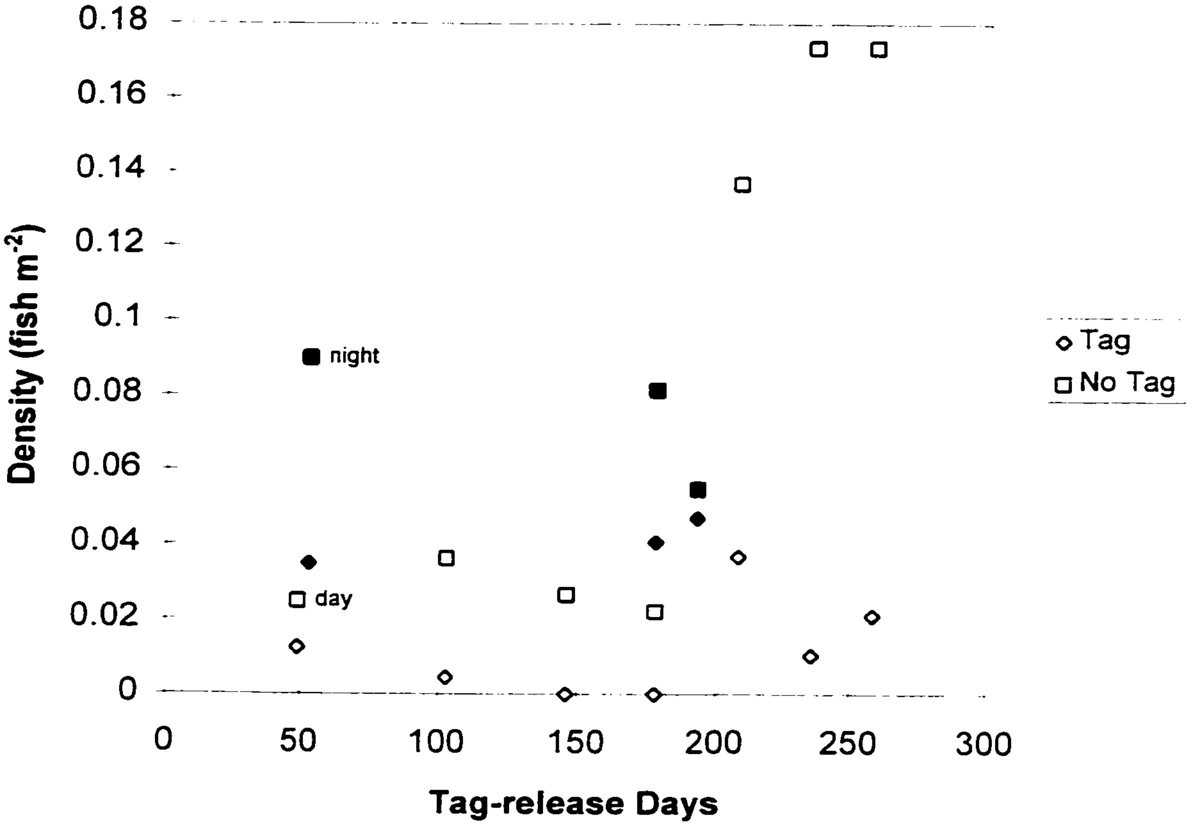


Figure 2.8. Densities of tagged and not tagged 1991 cohort juvenile rockfish on Boeing Creek Artificial Reef IRH central habitat, during day and night surveys.

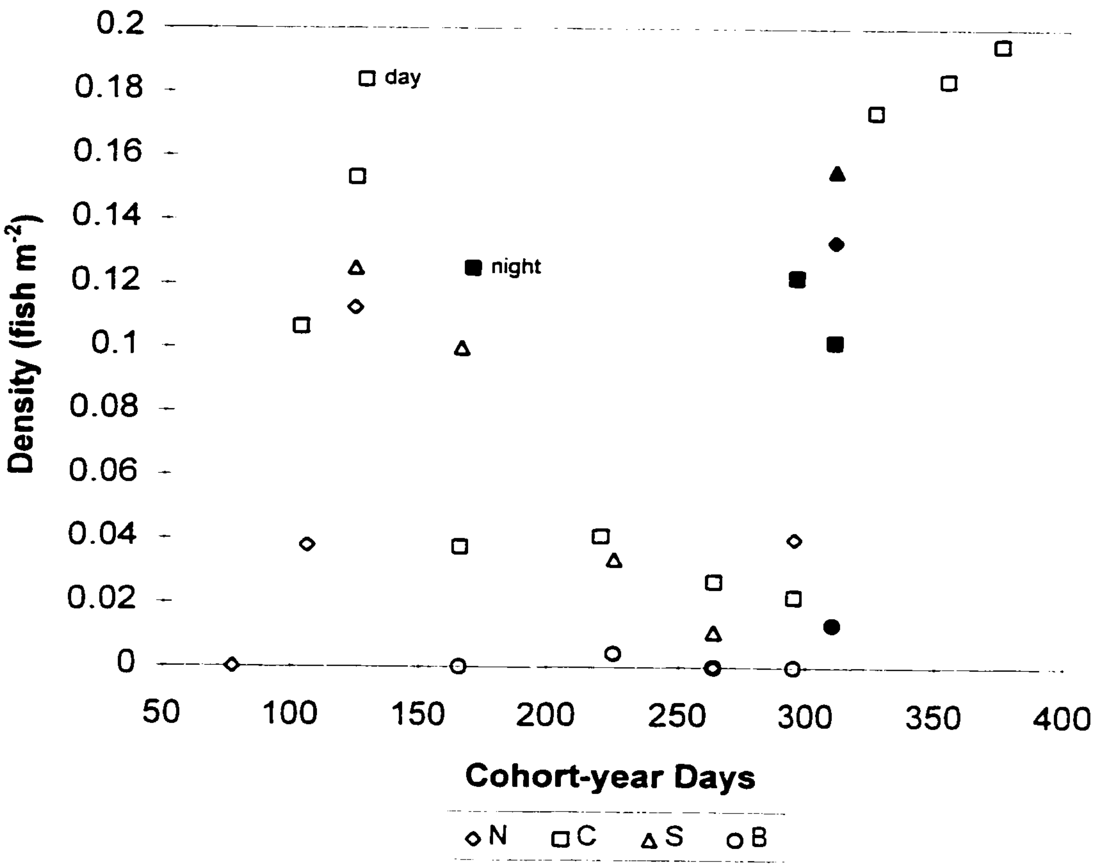


Figure 2.9. Densities of 1991 cohort juvenile rockfish on Boeing Creek Artificial Reef IRH north (N), central (C), south (S), and base (B) habitats, during day and night surveys.

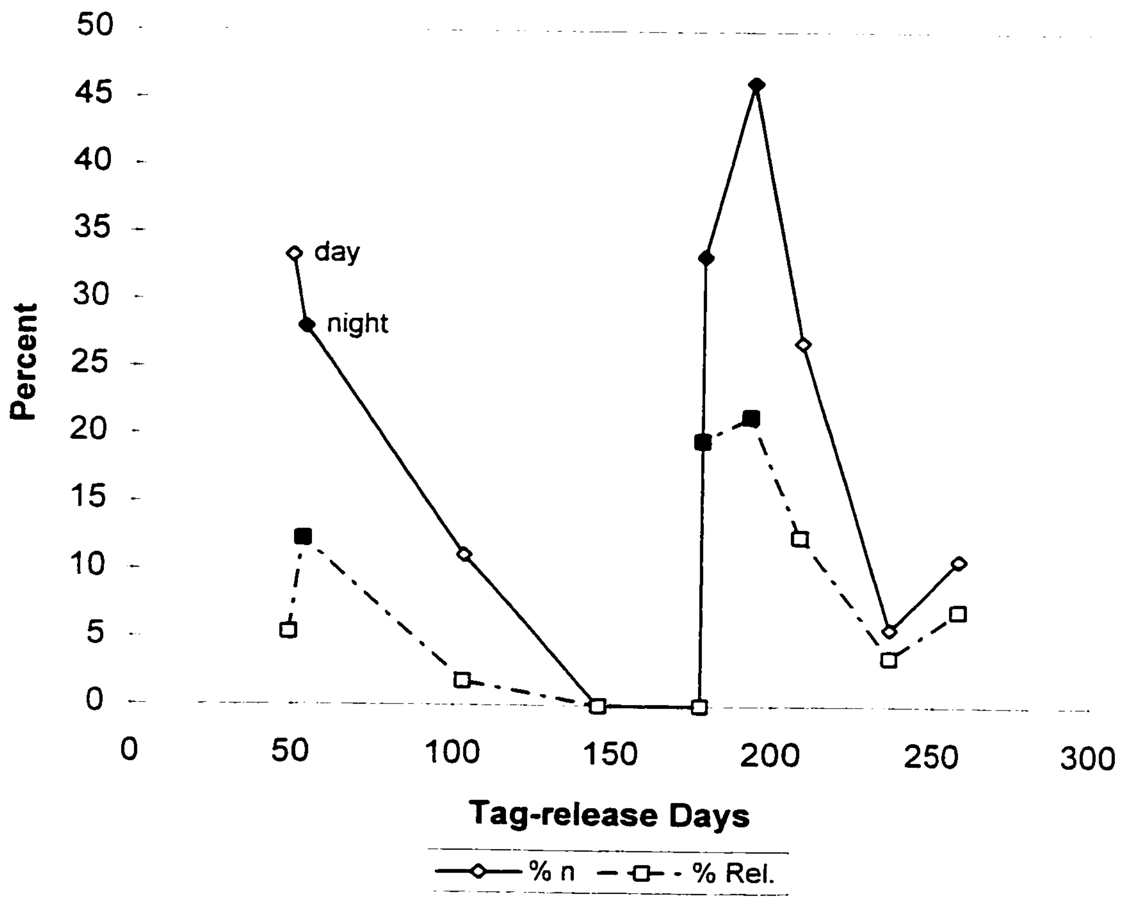


Figure 2.10. Recoveries of tagged 1991 cohort juvenile rockfish on Boeing Creek Artificial Reef IRH central habitat (10/25/91 to 7/9/92), as percent of survey (% n) and percent of total release (% Rel.), during day and night surveys.

central habitat, however the percent of the tags released that were recovered in each survey followed the same pattern (Figure 2.10).

### 1992 Tagging in Gedney Island Bull Kelp Habitat

The 246 juvenile rockfishes tagged with VIF tags in the left mid-dorsal region, and released in GIKM over the period October 12 to 22 (c-y d 104 to 114), were collected over five days from unquantified areas of the central portion of the habitat (Table 2.4). These juvenile rockfishes were identified as primarily quillback rockfish at the time of the collections, although some copper rockfish could have been included due to minor visual identification questions. The total tagged juvenile rockfishes ranged from 22 to 70 mm TL (average 43.0 ± 8.8 mm TL; Figure 2.11) and formed three tag release groups; October 12, 16-17, and 21-22. These three groups had relatively equal size ranges and the average sizes were not significantly different (ANOVA; $F = 3.615$, $p = 0.028$). These size similarities, combined with the short duration of the tagging period, justified treating the five tag releases as a single stage release; 0 d for the total tag release was considered as October 22 (c-y d 114) as 74.5% of the tagged fish were released in the October 21- 22 group.

The percent of the VIF tags recovered in the last four collection samples decreased even though more tagged juvenile rockfish were released in the central portion of GIKM (Figure 2.12). There was a minor increase to 3.2% of the tagged juveniles recovered in the survey at 19 d (c-y d 133), but subsequent surveys in GIKM at 27 d and 54 d (c-y d 141 and 168, respectively) did not recover any tagged fish, and the densities of juvenile rockfishes decreased (Table 2.4).

Table 2.4. Release and recovery of 1992 cohort juvenile quillback rockfish tagged with Visible Implant Fluorescent filament tags in Gedney Island kelp and macrophyte habitat (GIKM).

|  |  |  | Survey[3] |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | c-y d[1] | Tag d[2] | Location | Area | n | C. Tag Rel. | Tag Rec. | % Tag | % Tag Rel.[4] | Density[5] Tag | Density[5] n |
| 10/12/92 | 104 |  | GIKM |  | 28 | 28 |  |  |  |  |  |
| 10/16/92 | 108 |  | GIKM |  | 31 | 55 | 2 | 6.5 | 7.14 |  |  |
| 10/17/92 | 109 |  | GIKM |  | 11 | 64 | 2 | 18.18 | 3.64 |  |  |
| 10/21/92 | 113 |  | GIKM |  | 89 | 153 | 0 | 0 | 0 |  |  |
| 10/22/92 | 114 | 0 | GIKM |  | 95 | 247 | 1 | 1.1 | 0.4 |  |  |
| 11/10/92 | 133 | 19 | GIKM | 820 | 34 | 247 | 8 | 23.53 | 3.24 | 0.01 | 0.04 |
| 11/18/92 | 141 | 27 | GIKM | 1,240 | 32 | 247 | 0 | 0 | 0 | 0 | 0.03 |
| 12/15/92 | 168 | 54 | GIKM | 1,000 | 12 | 247 | 0 | 0 | 0 | 0 | 0.01 |
| 2/4/93 | 218 | 104 | GIAR orig. reef | 80 | 4 | 247 | 0 |  |  |  | 0.05 |
| 2/4/93 | 218 | 104 | ARH west hab. | 180 | 28 | 247 | 0 |  |  |  | 0.16 |
| 2/4/93 | 218 | 104 | IRH east hab. | 390 | 25 | 247 | 0 |  |  |  | 0.06 |
| 2/11/93 | 226 | 112 | IRH sand | 200 | 0 | 247 | 0 |  |  |  | 0 |
| 2/11/93 | 226 | 112 | IRH sand/rock | 15 | 12 | 247 | 0 |  |  |  | 0.8 |
| 2/11/93 | 226 | 112 | IRH east hab. | 75 | 16 | 247 | 0 |  |  |  | 0.21 |

[1] c-y d = cohort-year day; see Table 2.3.

[2] Days post-tagging and release.

[3] Location - see List of Abbreviations; area surveyed in $m^2$; cumulative tagged fish released (C. Tag Rel.); number (Tag Rec.) and percentage (% Tag) of tagged fish in the survey.

[4] Percentage of total tagged fish released that were in the survey.

[5] Tagged (Tag) and total (n) juvenile rockfish $m^{-2}$ in the survey.

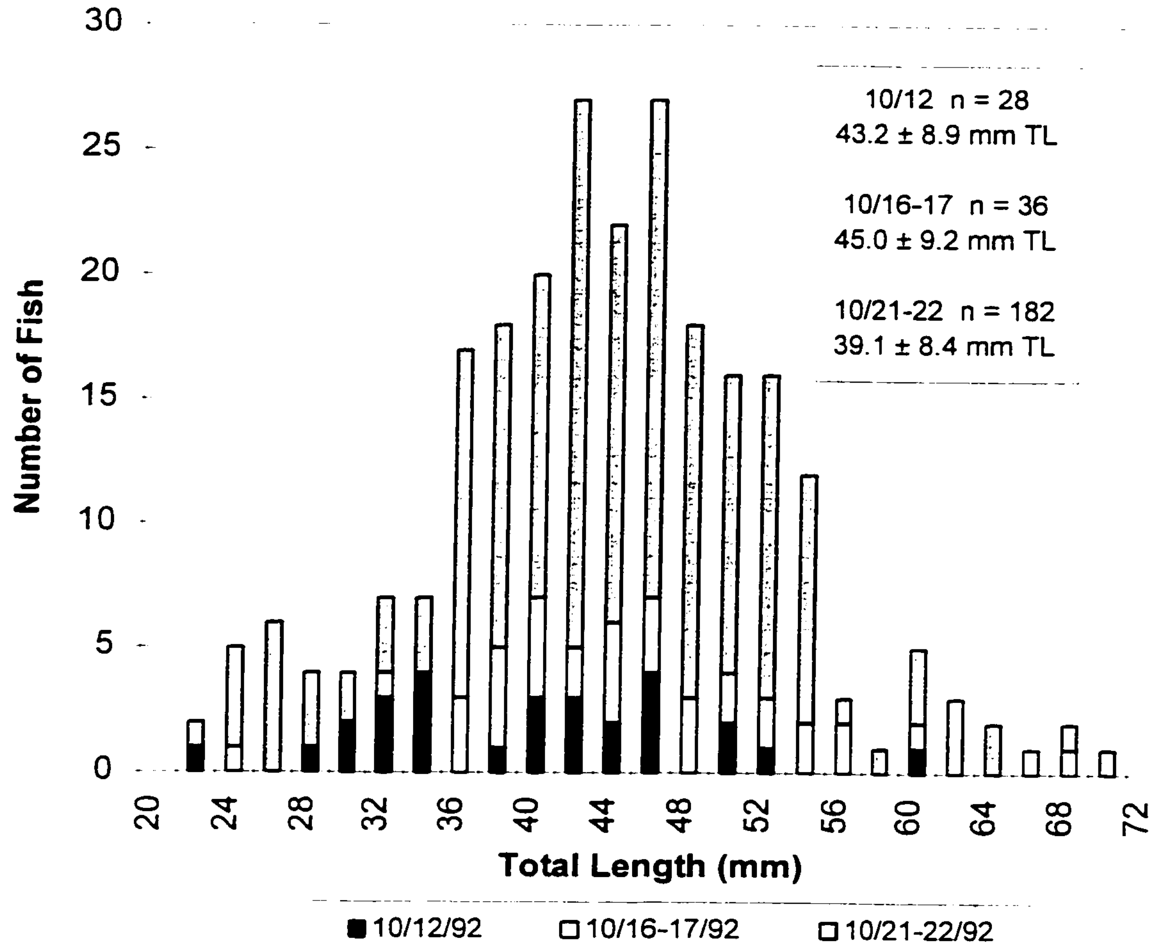


Figure 2.11. Length frequency distribution of 1992 cohort juvenile rockfish tagged in Gedney Island kelp and macrophyte habitat (GIKM).

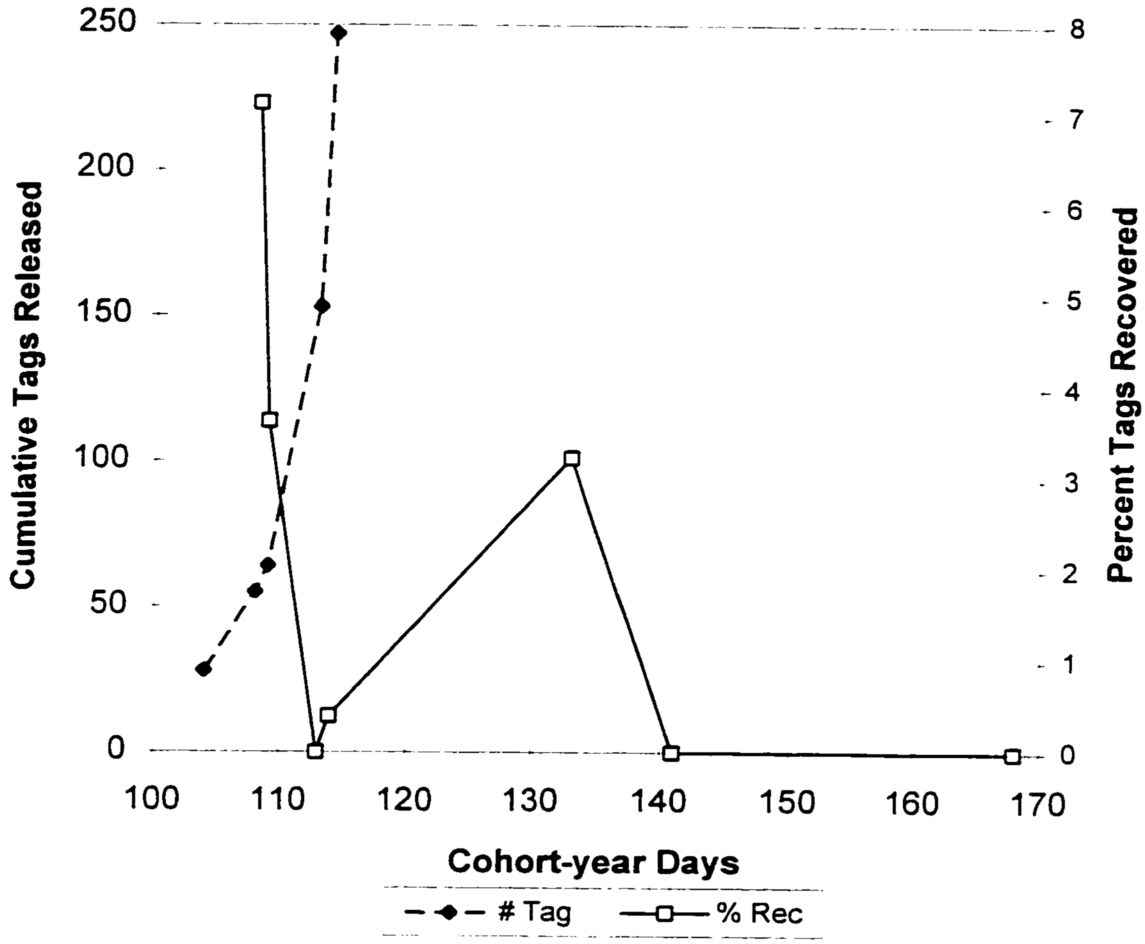


Figure 2.12. Number of tagged 1992 cohort juvenile rockfish (# Tag) released in Gedney Island kelp and macrophyte habitat (GIKM), and percent of tags recovered (% Rec.).

Surveys at 104 d (c-y d 218) of the IRH east habitat of GIAR, the offshore rocky-reef substrate nearest GIKM, and at 112 d (c-y d 226) of the IRH east habitat and the sand and a large natural rock between IRH and GIKM, did not recover any tagged fish (Table 2.4). The high density of untagged juvenile rockfish at the large natural rock (0.8 fish $m^{-2}$) at 112 d was an aggregation of apparently transient juveniles in a depression in the substrate formed under the rock by an octopus (*Octopus* sp).

### 1993 Tagging in Edmonds Bull Kelp Habitat

The two groups of juvenile quillback rockfish tagged and released in EKM on October 14 (c-y d 106) and November 5 (c-y d 128), were collected from unquantified areas of habitat in the central portion of EKM (Table 2.5). Although these groups were collected 22 days apart, their similar size ranges and average sizes indicate that they represented the same cohort; the 112 juveniles in the first group, with VIF tags in the left mid-dorsal region, averaged 71.4 ± 5.3 mm TL, and the 95 juveniles in the second group, with VIF tags in the right nape region, averaged 72.5 ± 5.8 mm TL (Figure 2.13). The different tag injection locations allowed temporal separation of tag recoveries from the two groups.

The 13 juvenile quillback rockfish from the 1993 cohort collected from MKM on November 8 (c-y d 131), that were VIF tagged and held in an aquarium to recheck the long-term effects of the tagging procedures, ranged from 58 to 93 mm TL, and averaged 75.9 ± 8.7 mm TL. These sizes were comparable to the two groups of juveniles tagged and released on EKM. VIF tag retention and survival in the MKM juveniles were both 100% at the last check at 129 d (c-y d 260) after tagging.

Table 2.5. Release and recovery of 1993 cohort juvenile quillback rockfish tagged with Visible Implant Fluorescent filament tags in Edmonds kelp and macrophyte habitat (EKM).

| | | | | Survey[3] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Time | c-y d[1] | Tag d[2] | Habitat | Area | n | C. Tag Rel. | Tag Rec. | % Tag | % Tag Rel.[4] | Den.[5] |
| 10/1/93 | Day | 93 | | K+M | 160 | 73 | | | | | 0.46 |
| 10/14/93 | Day | 106 | 0-L | K+M | | 112 | 112-L | | | | |
| 10/24/93 | Day | 116 | 10 | K+M | 240 | 27 | 112-L | 0 | | | 0.11 |
| 10/24/93 | Day | 116 | 10 | K+M | | 49 | 112-L | 2 | 4.8 | 1.8 | |
| 11/2/93 | Day | 125 | 19 | K+M | 140 | 7 | 112-L | 0 | | | 0.05 |
| 11/2/93 | Day | 125 | 19 | K+M | | 65 | 112-L | 2 | 3.1 | 1.8 | |
| 11/5/93 | Day | 128 | 22 | K+M | | 100 | 112-L | 5-L | 5 | 4.5 | |
| 11/5/93 | Day | 128 | 0-R | K+M | | 95 | 95-R | | | | |
| 11/14/93 | Day | 137 | 31-L, 9-R | K+M | | 24 | 207-T | 1-L | 4.2 | 0.9 | |
| 1/7/94 | Day | 191 | 85-L, 63-R | K+M | 620 | 0 | 207-T | | | | 0 |
| 1/7/94 | Day | 191 | 85-L, 63-R | P.R. | 55 | 0 | 207-T | | | | 0 |
| 1/20/94 | Night | 204 | 98-L,76-R | K+M | 240 | 0 | 207-T | | | | 0 |
| 1/20/94 | Night | 204 | 98-L,76-R | Sand | 90 | 0 | 207-T | | | | 0 |
| 1/20/94 | Night | 204 | 98-L,76-R | P.R. | 55 | 5 | 207-T | 0 | | | 0.09 |
| 2/1/94 | Night | 216 | 110-L, 88-R | K+M | 165 | 0 | 207-T | | | | 0 |
| 2/1/94 | Night | 216 | 110-L, 88-R | P.R. | 55 | 4 | 207-T | 0 | | | 0.07 |
| 2/2/94 | Day | 217 | 111-L, 89-R | K+M | 220 | 0 | 207-T | | | | 0 |

[1] c-y d = cohort-year day; see Table 2.3.

[2] Days post-tag release; tag in left (L) or right (R) nape.

[3] K+M = bull kelp and macrophyte; P.R. = patch reef; survey area in m$^2$; cumulative tags released (C. Tag Rel.), T = total tags; number (Tag Rec.) and percent (% Tag) of tagged fish in the survey.

[4] Percent of tagged fish released in the survey.

[5] Total juvenile rockfish m$^{-2}$ in the survey.

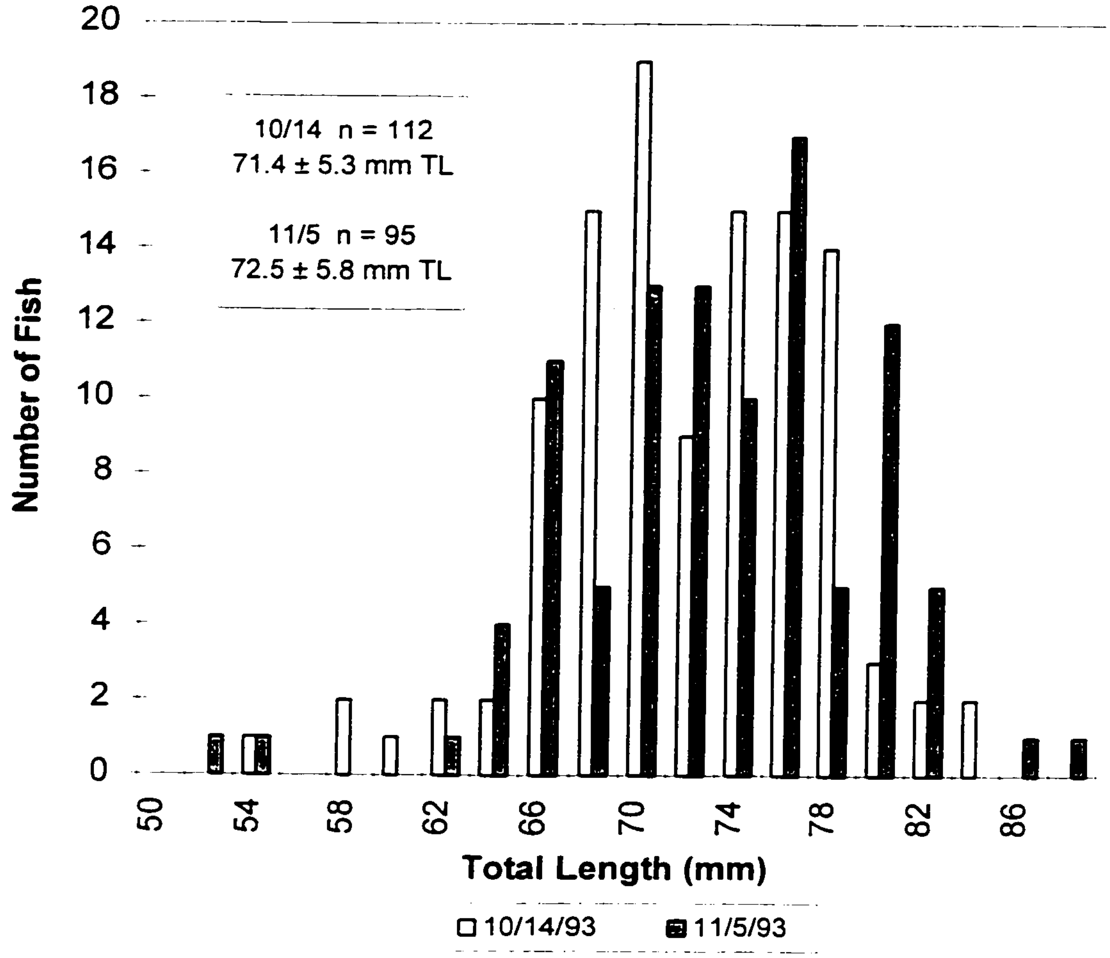


Figure 2.13. Length frequency distribution of 1993 cohort juvenile quillback rockfish tagged in Edmonds kelp and macrophyte habitat (EKM).

Transect surveys for juvenile quillback rockfish in EKM at 10 d (n = 27) and 19 d (n = 7) after the release of the first tagged group did not recover any tags (Table 2.5); however, rapid random searches of larger areas in EKM on these days (n = 49 and n = 65, respectively) each recovered two tagged juveniles. This indicated that the juvenile quillback rockfish in EKM had dispersed throughout the habitat after the tag release on c-y d 106, and that the limited areas covered by the transect surveys were not adequate to encounter sufficient numbers of juveniles to find tagged fish at the diluted densities. The rapid random searches at 10 d, 19 d and 31 d after the release of the first group of tagged fish indicated that approximately 1 in 28 juveniles in EKM were tagged (Table 2.5). Transect surveys of the natural benthic habitat of EKM at c-y d 191 (diurnal), 204 (nocturnal), 216 (nocturnal), and 217 (diurnal) did not find any juvenile quillback rockfish from the first tagged group.

The collection of 100 juvenile quillback rockfish from the central portion of EKM at c-y d 128 (22 d after the first tag release) recovered 5 tagged fish from the first group; the remaining 95 juveniles formed the second tag release group. A random search at 9 d, and transect surveys at 63 d, 76 d, 88 d, and 89 d (c-y d 191, 204, 216, and 217, respectively), after the release of the second tagged group, did not recover any tagged juveniles from the second group (Table 2.5; Figure 2.14).

During the tag recovery transect survey in EKM on c-y d 128 (November 2), measurements of the thickness of the layer of benthic drift macrophytes were made at 1 m intervals along a 55 m transect line, from the nearshore boundary, to the offshore boundary, of the bull kelp bed. The drift macrophyte habitat was

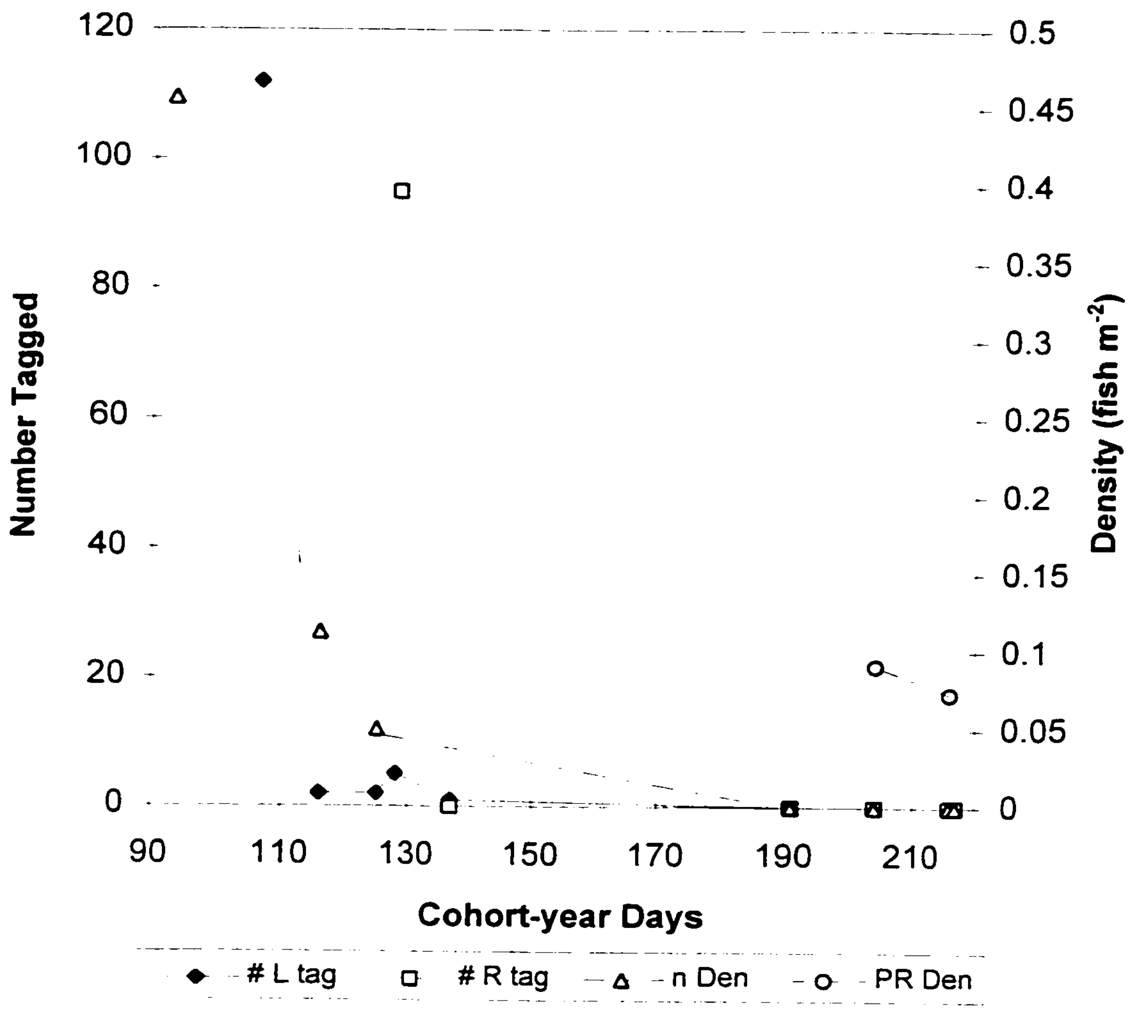


Figure 2.14. Number of left (# L tag) and right (# R tag) tagged 1993 cohort juvenile quillback rockfish recovered in Edmonds kelp and macrophyte habitat (EKM), and total densities of juveniles in EKM (n Den.) and on patch reef habitats (PR Den.).

composed of detached *Ulva* spp., *L. saccharina*, *Agarum* sp., and other benthic forms common in understory vegetation of EKM, and was distributed throughout EKM as a rather dense but fluid layer suspended over the substrate. The thickness of the layer of drift habitat ranged from 0 to 23 cm, average 12.4 ± 6.1 cm, and varied rather uniformly along the transect line (Figure 2.15).

Quantified surveys of the patch reefs and surrounding natural benthic habitats in EKM were conducted on c-y d 191 (diurnal), 204 (nocturnal),and 216 (nocturnal; Table 2.5). No juvenile quillback rockfish were found in the surveys on c-y d 191; in the surveys on c-y d 204, five juvenile quillback rockfish were on the north patch reef, and none were on the south patch reef, or on the natural habitats. Juvenile quillback rockfish remained on the north patch reef in the final survey on c-y d 216 (Figure 2.14), well after the benthic macrophytes had virtually disappeared.

### 1994 Recruitment to Natural Habitats

Surveys were started on July 26 (c-y d 26) to determine the temporal and spatial elements in the settlement of pelagic juvenile copper rockfish and quillback rockfish to nearshore benthic habitats in northcentral Puget Sound. The earliest surveys in EKM and MKM (from c-y d 26 to c-y d 40) did not find any juvenile rockfishes in 1,644 $m^2$ of benthic macrophyte habitat in the beds of bull kelp, 400 $m^2$ of bull kelp habitat in mid-water and on the surface, and 388 $m^2$ of benthic eelgrass habitat on the perimeters of the bull kelp beds (Table 2.6).

The first juvenile quillback rockfish recruits were found in the ARH and IRH areas of BCAR on August 23 (c-y d 54) associated with detached benthic macrophytes (*L. saccharina* and *D. munda*) that were drifting in the tidal current along the

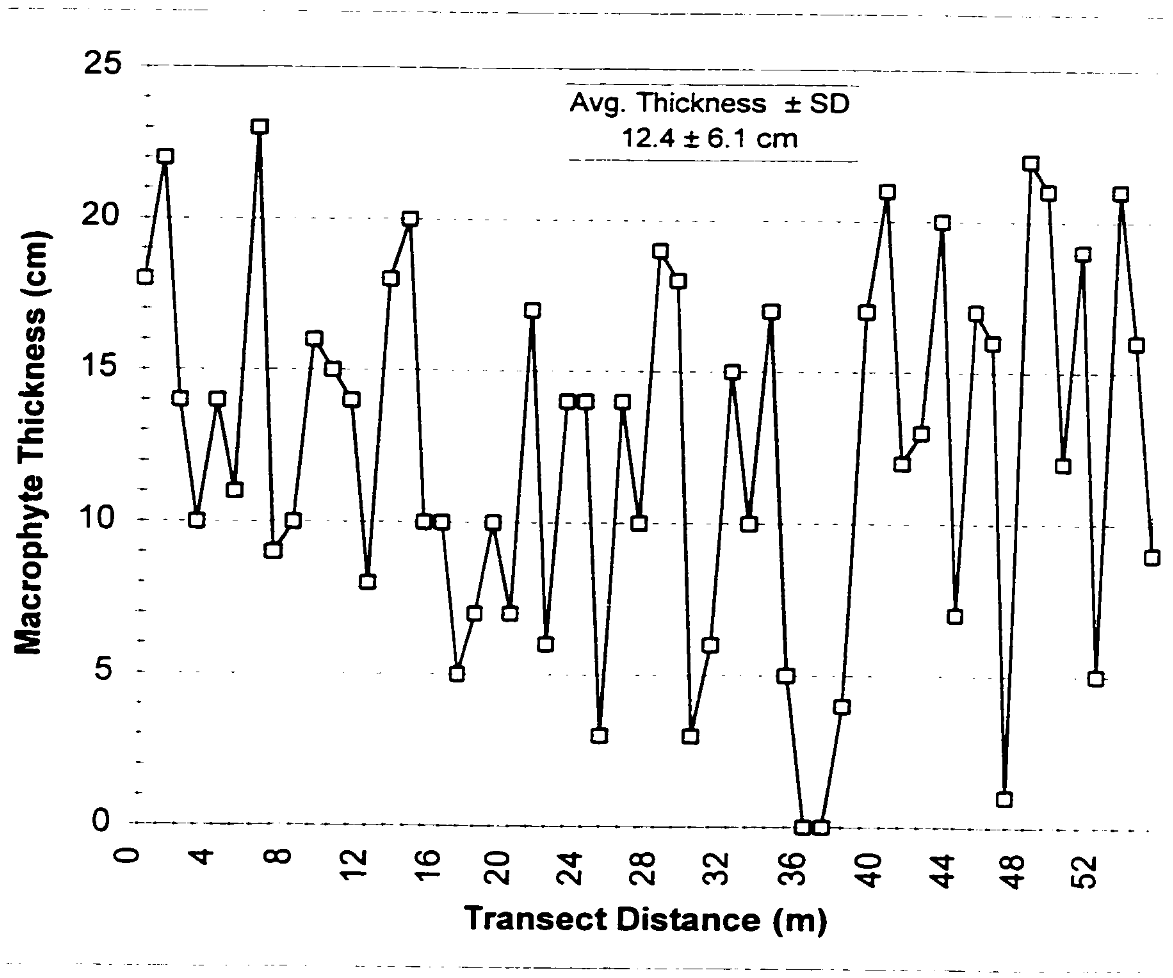


Figure 2.15. Thickness of benthic drift macrophyte layer in Edmonds kelp and macrophyte habitat (EKM) on November 2, 1993.

Table 2.6. Surveys of natural habitats for substrate associated recruitment of 1994 cohort juvenile quillback rockfish in northcentral Puget Sound.

| 1994 | | Survey [2] | | | | Total Length[3] | |
|---|---|---|---|---|---|---|---|
| Date | c-y d[1] | Location | Habitat | Area | n | Range | Avg. ± SD |
| 7/26 | 26 | EKM | Benthic macro. | 500 | 0 | | |
| 7/26 | 26 | EKM | Bull kelp | 200 | 0 | | |
| 7/27 | 27 | MKM | Benthic macro. | 344 | 0 | | |
| 7/27 | 27 | MKM | Bull kelp | 200 | 0 | | |
| 7/27 | 27 | MKM | Eelgrass | 228 | 0 | | |
| 8/9 | 40 | EKM | Benthic macro. | 800 | 0 | | |
| 8/9 | 40 | EKM | Eelgrass | 100 | 0 | | |
| 8/23 | 54 | BCAR ARH | Drift macro. | 3 | 3 | 35-?? | ?? |
| 8/23 | 54 | BCAR ARH | Bull kelp | 48 | 0 | | |
| 8/23 | 54 | BCAR ARH | Sand | 12 | 0 | | |
| 8/23 | 54 | BCAR ARH | Reef | 60 | 0 | | |
| 8/23 | 54 | BCAR IRH | Drift macro. | 2 | 8 | 40-50 | |
| 8/23 | 54 | BCAR IRH | Bull kelp | 72 | 0 | | |
| 8/23 | 54 | BCAR IRH | Eelgrass | 50 | 0 | | |
| 8/23 | 54 | BCAR IRH | Sand | 12 | 0 | | |
| 8/23 | 54 | BCAR IRH | Reef | 180 | 0 | | |
| 8/24 | 55 | BCAR ARH | Drift macro. | 5 | 8 | 31-56 | 44.8±6.5 |
| 8/24 | 55 | BCAR ARH | Bull kelp | 60 | 0 | | |
| 8/24 | 55 | BCAR ARH | Eelgrass | 25 | 0 | | |
| 8/24 | 55 | BCAR ARH | Sand | 12 | 0 | | |
| 8/24 | 55 | BCAR ARH | Reef | 72 | 0 | | |
| 8/28 | 59 | EKM | Benthic macro. | ?? | 10 | 55-71 | 60.3±5.2 |
| 9/1 | 63 | MKM | Benthic macro. | ?? | 13 | 50-65 | 57.9±4.4 |
| 9/10 | 72 | BCAR IRH | Drift macro. on reef | 2 | 3 | 50-60 | 56.7±5.8 |
| 10/21 | 113 | BCAR IRH | Reef | 48 | 7 | 55-75 | 65.7±7.3 |

[1] c-y d = cohort-year day; see Table 2.3.

[2] Location - see List of Abbreviations; macro. = macrophytes; area surveyed in $m^2$; n = number of juvenile rockfish.

[3] Length in mm; average ± standard deviation.

sand habitat, at 6 to 9 m depths (Table 2.6). In the ARH area, three aggregations of benthic drifting macrophytes (approximately 1 $m^2$ each) were near the shallowest portions of the north, central, and south habitats, and had become fouled on plastic pipe stakes placed in the sand during the construction of the ARH. Each aggregation of macrophytes contained one juvenile quillback rockfish, the smallest measured 35 mm TL. In the IRH area, one aggregation of drifting macrophytes (approximately 2 $m^2$) was adjacent to the shallowest portion of the central habitat, and had become fouled on rocks from the central habitat. This aggregation of macrophytes contained 8 juvenile quillback rockfish, ranging approximately 40 to 50 mm TL. Concurrent surveys on c-y d 54 of 240 $m^2$ of reef refuge substrate on the ARH and IRH, and 120 $m^2$ of bull kelp habitat associated with the ARH and IRH, as well as adjacent sand and eelgrass habitats (24 $m^2$ and 50 $m^2$, respectively), did not find any juvenile rockfishes.

Surveys of the ARH area of BCAR on August 24 (c-y d 55) found three aggregations of detached benthic macrophytes (*L. saccharina*, *A. fimbriatum*, and *D. munda*), which had become fouled on plastic pipe stakes near the shallow portions of the north and central habitats, at 4 m depth. One of the aggregations of detached macrophytes was approximately 1 $m^2$, and had one associated juvenile quillback rockfish which was observed actively feeding on small crustaceans associated with the macrophyte. Two of the aggregations of macrophytes were approximately 2 $m^2$, and had two and five associated juvenile quillback rockfish, respectively. Concurrent surveys on c-y d 55 of 72 $m^2$ of reef refuge substrate on the ARH, and 60 $m^2$ of bull kelp habitat associated with the ARH, as well as adjacent sand and eelgrass habitats (12 $m^2$ and 25 $m^2$, respectively), did not find any juvenile rockfishes.

The eight juvenile quillback rockfish from the ARH area of BCAR ranged from 31 to 56 mm TL, average 44.8 ± 6.5 mm TL (Table 2.6), and were confirmed to be quillback rockfish through development of distinctive morphological features and coloration patterns (Chen 1986, Matarese et al. 1989) in an 33 d aquarium grow-out study. These captive juveniles grew to an average 55.8 ± 9.1 mm TL ($n = 5$, range 45-65 mm TL), for an average growth rate of 0.33 mm $d^{-1}$, under liberal feeding conditions.

Collections of juvenile rockfishes at EKM on August 28 (c-y d 59) and at MKM on September 1 (c-y d 63) confirmed recruitment of juvenile quillback rockfish to the benthic macrophyte habitats in these bull kelp beds. The juvenile quillback rockfish in EKM and MKM were larger (size range and average size, 55 to 71 mm TL and 60.3 ± 5.2 mm TL, 50 to 65 mm TL and 57.9 ± 4.4 mm TL, respectively) than the recruits associated with the drifting benthic aggregations of macrophytes at BCAR (Table 2.6).

### Temporal Size Ranges of Juvenile *Sebastes*

The best estimates of the temporal size ranges for juvenile rockfishes in central Puget Sound are given by the measured samples of juveniles (primarily quillback rockfish, but including some copper rockfish) from the tagging of the 1990-1993 cohorts, and the collections for identification grow-out studies of the 1994 cohort (Table 2.7). This information, combined with collections from the 1991 and 1992 cohorts (Washington Department of Fish and Wildlife, unpublished), indicated some temporal and spatial variability, however, the maximum sizes of the juvenile rockfishes over time provided improved estimates of the length limits (see Identification and Enumeration of *Sebastes*) for separating juveniles from

Table 2.7. Measured length samples of juvenile rockfishes[1] from the 1991-1994 cohorts in northcentral Puget Sound.

| Cohort-year | c-y d[2] | Location[3] | n | Total Length[4] Avg. | SD | Min. | Max | Data[5] |
|---|---|---|---|---|---|---|---|---|
| 1994 | 55 | BCAR - drift macrophytes | 8 | 44.8 | 6.5 | 31 | 56 | A |
| 1994 | 59 | EKM | 10 | 60.3 | 5.2 | 55 | 71 | A |
| 1994 | 63 | MKM | 13 | 57.9 | 4.4 | 50 | 65 | A |
| 1992 | 104 | GIKM | 28 | 39.1 | 8.4 | 22 | 60 | A |
| 1993 | 106 | EKM | 112 | 71.4 | 5.3 | 54 | 84 | A |
| 1992 | 109 | GIKM | 36 | 45 | 9.2 | 24 | 68 | A |
| 1992 | 114 | GIKM | 182 | 43.2 | 8.9 | 22 | 70 | A |
| 1991 | 117 | BCAR | 54 | 61.3 | 7.4 | 40 | 73 | B |
| 1990 | 124 | BCAR | 62 | 63.6 | 11.1 | 47 | 94 | A |
| 1993 | 128 | EKM | 95 | 72.5 | 5.8 | 52 | 88 | A |
| 1993 | 131 | MKM | 13 | 75.9 | 8.7 | 58 | 93 | A |
| 1991 | 325 | BCAR | 43 | 84.9 | 9.1 | 50 | 101 | B |

[1] Primarily quillback rockfish.

[2] c-y d = cohort-year day; see Table 2.3.

[3] Location - see List of Abbreviations.

[4] Length in mm; Avg. = average length; SD = standard deviation; Min. = minimum length; Max. = maximum length.

[5] A = this Dissertation research; B = Washington Department of Fish and Wildlife, unpublished.

smaller members of the previous cohort, especially late in the cohort-year (Figure 2.16).

Nearshore natural macrophyte habitats, which contained few rockfishes from previous cohorts due to the natural deterioration of the biogenic complexity of the habitats, provided nine of the 12 measurement samples from these cohorts (Table 2.7). This reduced the potential for including juvenile rockfishes from more than one cohort in each sample. The maximum sizes of 71 mm TL at c-y d 59, 84 mm TL at c-y d 106, 94 mm TL at c-y d 124, and 101 mm TL at c-y d 324, demonstrated that length interval estimates for juvenile rockfishes in central Puget Sound habitats should conservatively include fish of these lengths prior to these dates. In addition, lengths of juvenile rockfishes encountered during transect and quadrate surveys were rounded up to the next cm interval (see Identification and Enumeration of *Sebastes*), resulting in, for example, fish >70 mm TL being included in the 80 mm interval. These length data and survey criteria resulted in the following length intervals for designating juveniles in the 1994 cohorts of quillback rockfish and copper rockfish in surveys on artificial reef habitats: ≤80 mm TL up to c-y d 75, ≤90 mm TL for c-y d 75-100, ≤100 mm TL for c-y d 101-200, and ≤110 mm TL for c-y d 201-365.

## Rugosity of Artificial Reef Habitats

The rugosity values for BCAR and GIAR (Table 2.8) were normally distributed (BCAR - L K-S test; D = 0.219, p = 0.118; GIAR - L K-S test; D = 0.156, p = 0.157) and had homogeneous variances (BCAR - L test; F = 0.535, p = 0.481; GIAR - L test; F = 1.127, p = 0.272). There were no significant differences in the quadrate rugosity values for the BCAR ARH and IRH base habitats (F-test; F =

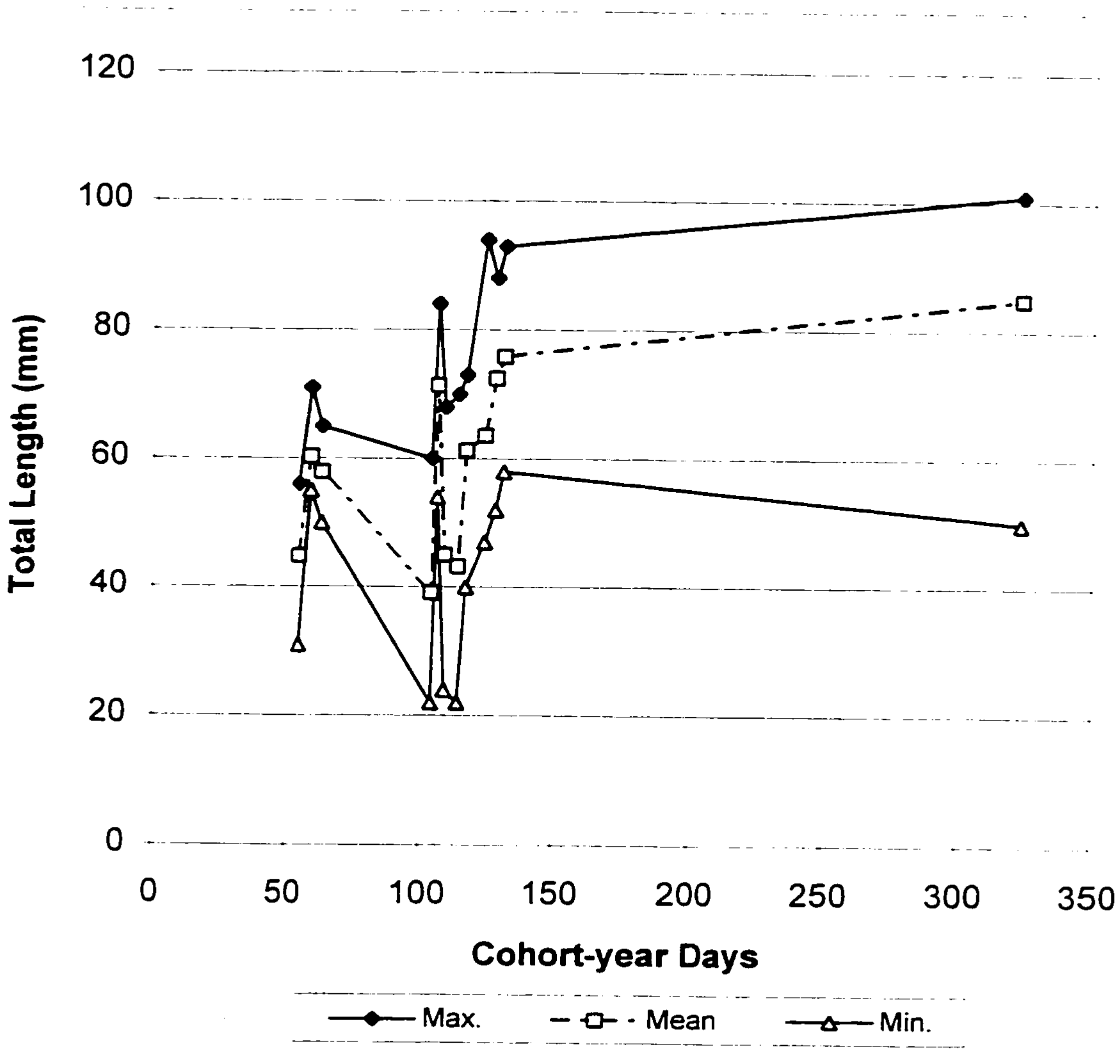


Figure 2.16. Maximum (Max.), mean, and minimum (Min.) lengths from measured samples of substrate associated 1991-1994 cohort juvenile rockfish from central Puget Sound.

Table 2.8. Rugosity values of the survey quadrates on Boeing Creek Artificial Reef (BCAR) and Gedney Island Artificial Reef (GIAR) ARH and IRH.

| BCAR[1] | | | |
|---|---|---|---|
| ARH | ARH | IRH | IRH |
| Quad.[2] | Rugos.[3] | Quad.[2] | Rugos.[3] |
| B 1 | 4951.25 | B 1 | 4849.75 |
| B 2 | 3109.75 | B 2 | 3379.5 |
| B 3 | 8207 | B 2 | 5360.75 |
| B 4 | 10050.3 | B 4 | 5074.25 |
| B 5 | 5375 | B 5 | 7562.25 |
| B 6 | 6933 | B 6 | 8482 |

| | BCAR[1] | |
|---|---|---|
| | ARH - B | IRH - B |
| Avg.[4] | 6437.71 | 5784.75 |
| SD[5] | 2483.56 | 1885.67 |

| GIAR[1] | | | |
|---|---|---|---|
| ARH | ARH | ARH | ARH |
| Quad.[2] | Rugos.[3] | Quad.[2] | Rugos.[3] |
| E 1 | 9009.25 | B 1 | 5039.5 |
| E 2 | 3220.75 | B 2 | 3651 |
| E 3 | 4509.5 | B 3 | 11082.8 |
| E 4 | 2149.25 | B 4 | 4081.25 |
| E 5 | 3522.75 | B 5 | 3694 |
| E 6 | 5732.5 | | |

| | GIAR[1] | |
|---|---|---|
| | ARH - E | ARH - B |
| Avg.[4] | 4690.67 | 5509.7 |
| SD[5] | 2439.34 | 3165.12 |

| GIAR[1] | | | |
|---|---|---|---|
| IRH | IRH | IRH | IRH |
| Quad.[2] | Rugos.[3] | Quad.[2] | Rugos.[3] |
| E 1 | 2065.5 | B 1 | 4865 |
| E 2 | 9076 | B 2 | 6522.5 |
| E 3 | 5225.75 | B 3 | 2736.75 |
| E 4 | 4857.5 | B 4 | 5405 |
| E 5 | 6439.5 | B 5 | 5850.5 |
| E 6 | 4919.75 | B 6 | 4435 |

| | GIAR[1] | |
|---|---|---|
| | IRH - E | IRH - B |
| Avg.[4] | 5430.67 | 4969.13 |
| SD[5] | 2291.82 | 1316.01 |

1] See List of Abbreviations.

2] Survey quadrate; B = base habitat; E = east habitat.

3] Rugosity value in $cm^2$; measure of substrate complexity.

4} Avg. = average rugosity value.

5] SD = standard deviation.

0.263, p = 0.619), or in the rugosity values for the GIAR ARH east and base habitats, and the GIAR IRH east and base habitats (F-tests; F = 0.236, p = 0.639, and F = 0.183, p = 0.679, respectively). Within GIAR, there were no significant differences in the quadrate rugosity values for the ARH and IRH (F-test; F = 0.021, p = 0.886). The ability of the construction techniques used to form the recruitment substrates (see Pilot Study of Refuge Habitat Parameters) to create similar habitats in different regions, is further demonstrated by there being no significant differences in the quadrate rugosity values for the BCAR ARH and IRH base habitats, and the GIAR ARH and IRH east and base habitats (F-test; F = 0.430, p = 0.824).

The quadrates on the BCAR ARH and IRH north, central, and south habitats were not included in the rugosity measurements, as they were removed from the surveys due to intrusion of moving sand substrate (see Quadrate Surveys, and 1994 Macrophyte and Substrate Profiles of Artificial Reefs). The estimated variable of the amount of rock habitat within the quadrates, was used in place of the substrate rugosity values of the quadrates for these habitats; due to the frequent changes in the exposure of the rock substrate, it was not feasible to determine the quadrate rugosity values for each survey.

### 1994 Macrophyte and Substrate Profiles of Artificial Reefs

Surveys of the percent coverage of the quadrate surface areas by benthic macrophytes, the number of bull kelp stipes in the quadrates, and the percent of the quadrate areas that were rock substrate, were conducted on BCAR ARH north, central, and south habitats, and the IRH central and south (bull kelp only) habitats, on c-y d 72 (September 10; Appendix III). There were no differences between these ARH and IRH habitats in average coverage of the quadrates by benthic macrophytes (t-test, arcsine transformation; $|t| = 0.267$, $p = 0.792$; Figures 2.17 and 2.18), in the average amount of rock substrate in the quadrates (t-test, arcsine transformation; $|t| = 0.201$, $p = 0.842$; Figures 2.19 and 2.20), or in the average number of bull kelp stipes (t-test; $|t| = 0.659$, $p = 0.516$; Figures 2.17 and 2.18).

It was noted at the start of the BCAR surveys (c-y d 53) that the rock substrates of the ARH and IRH north, central, and south habitats were being covered by unusual movements of the natural sand substrate (see Quadrate Surveys), severely reducing the refuge potential of these habitats. Repeat surveys on the ARH habitats on c-y d 115 showed no difference in the average coverage of the benthic macrophytes in the quadrates in 43 d (paired t-test, arcsine transformation; $|t| = 0.678$, $p = 0.511$; Figure 2.17), but significant reduction in the average amount of the quadrate areas that were rock substrate (paired t-test, arcsine transformation; $|t| = 2.873$, $p = 0.014$; Figure 2.19). Repeat surveys on the IRH central habitat on c-y d 113 also showed no significant difference in average benthic macrophyte coverage in the quadrates in 41 d (paired t-test, arcsine transformation; $|t| = 1.786$, $p = 0.102$; Figure 2.18), and significant reduction in the amount of rock substrate in the quadrates (paired t-test, arcsine transformation; $|t| = 5.825$, $p < 0.001$; Figure 2.20). The number of bull kelp stipes in the ARH and IRH quadrates were not affected by the intrusion of the sand substrate during these periods.

Surveys of the percent coverage of the quadrate surface areas by benthic macrophytes were conducted on the GIAR ARH and IRH east and base habitats on c-y d 68 (Appendix III). There were significant differences in the percent coverage of benthic macrophytes between the ARH east and base habitats, and

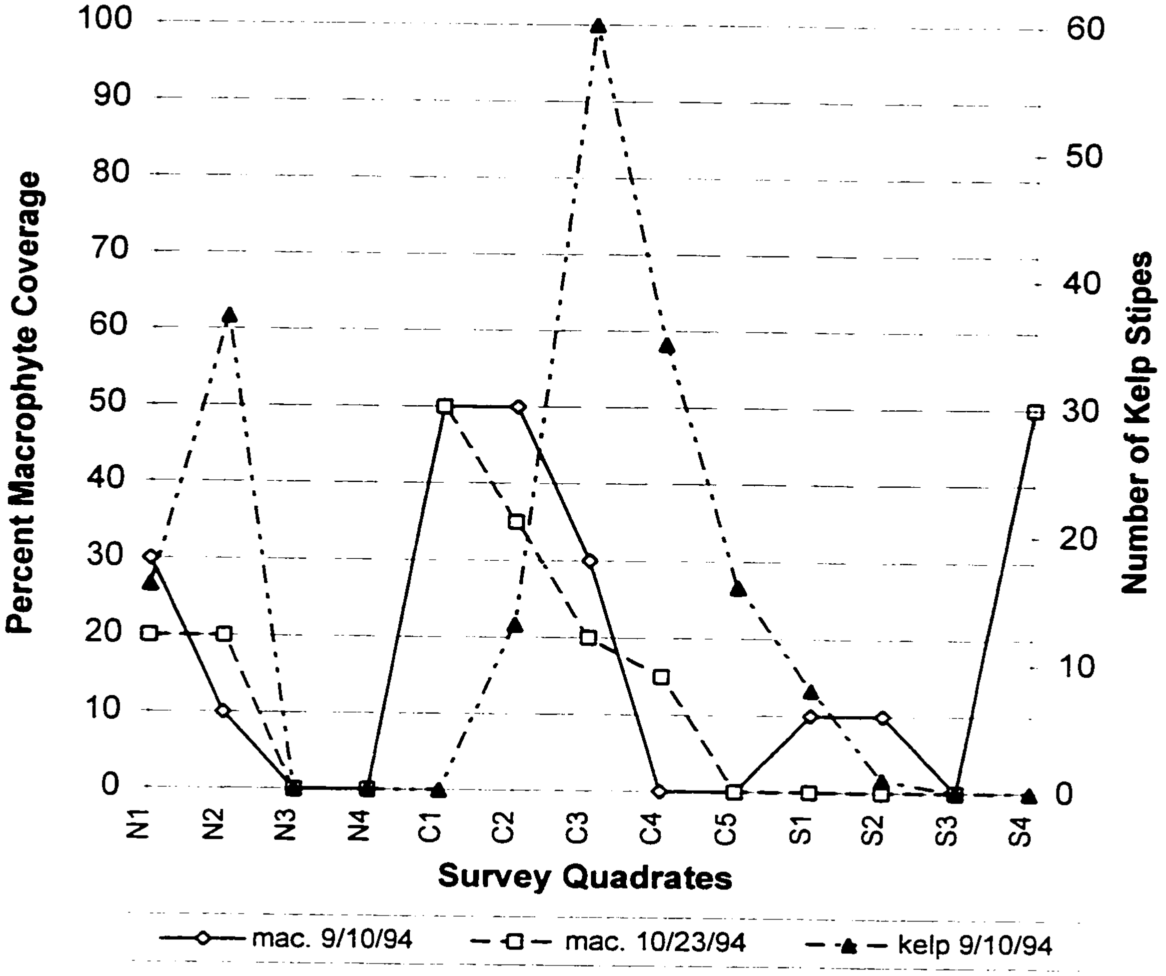


Figure 2.17. Percent macrophyte coverage (mac.) and number of bull kelp stipes (kelp), on Boeing Creek Artificial Reef ARH north (N), central (C), and south (S) habitats.

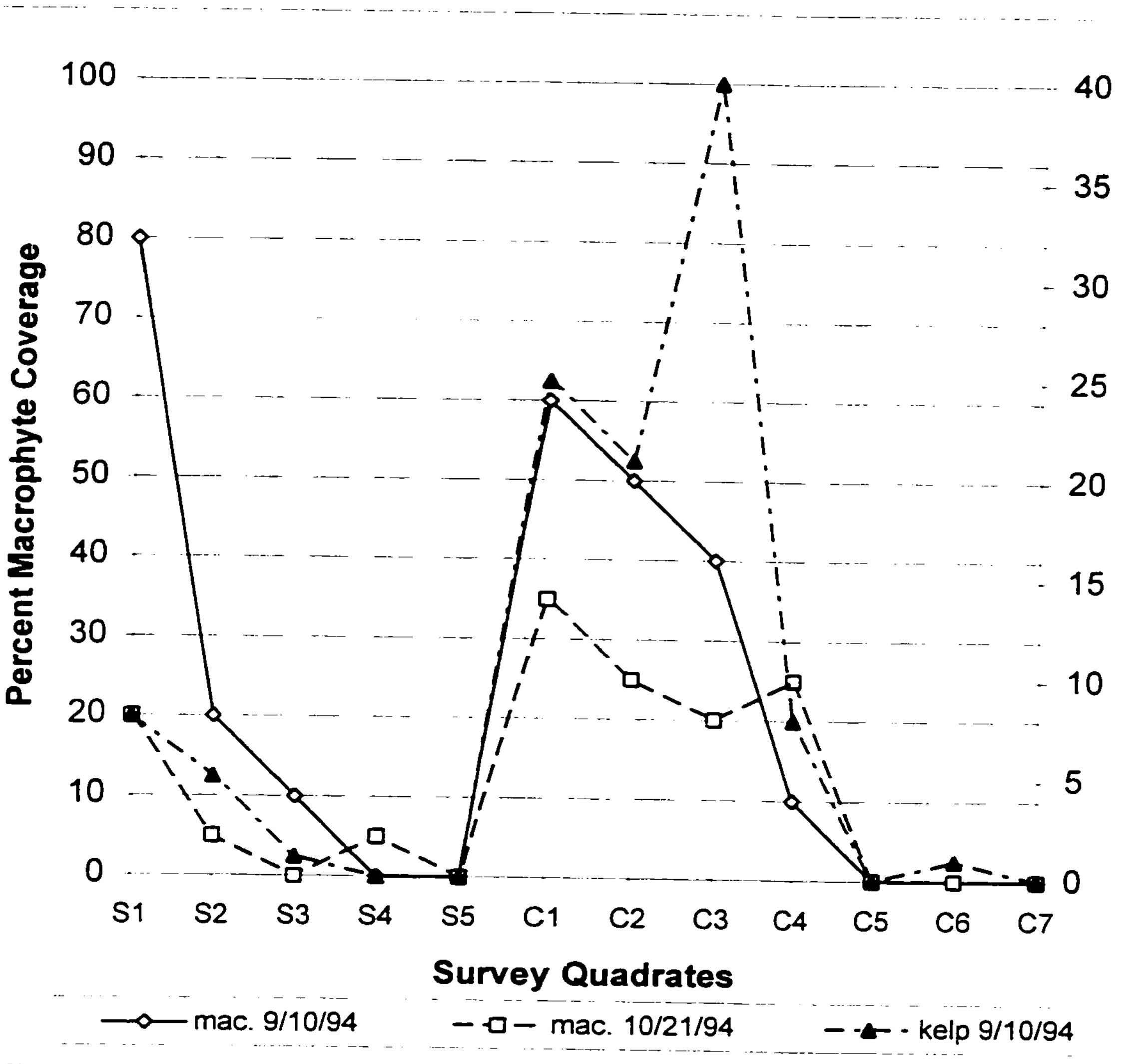


Figure 2.18. Percent macrophyte coverage (mac.) and number of bull kelp stipes (kelp), on Boeing Creek Artificial Reef IRH central (C) and south (S) habitats.

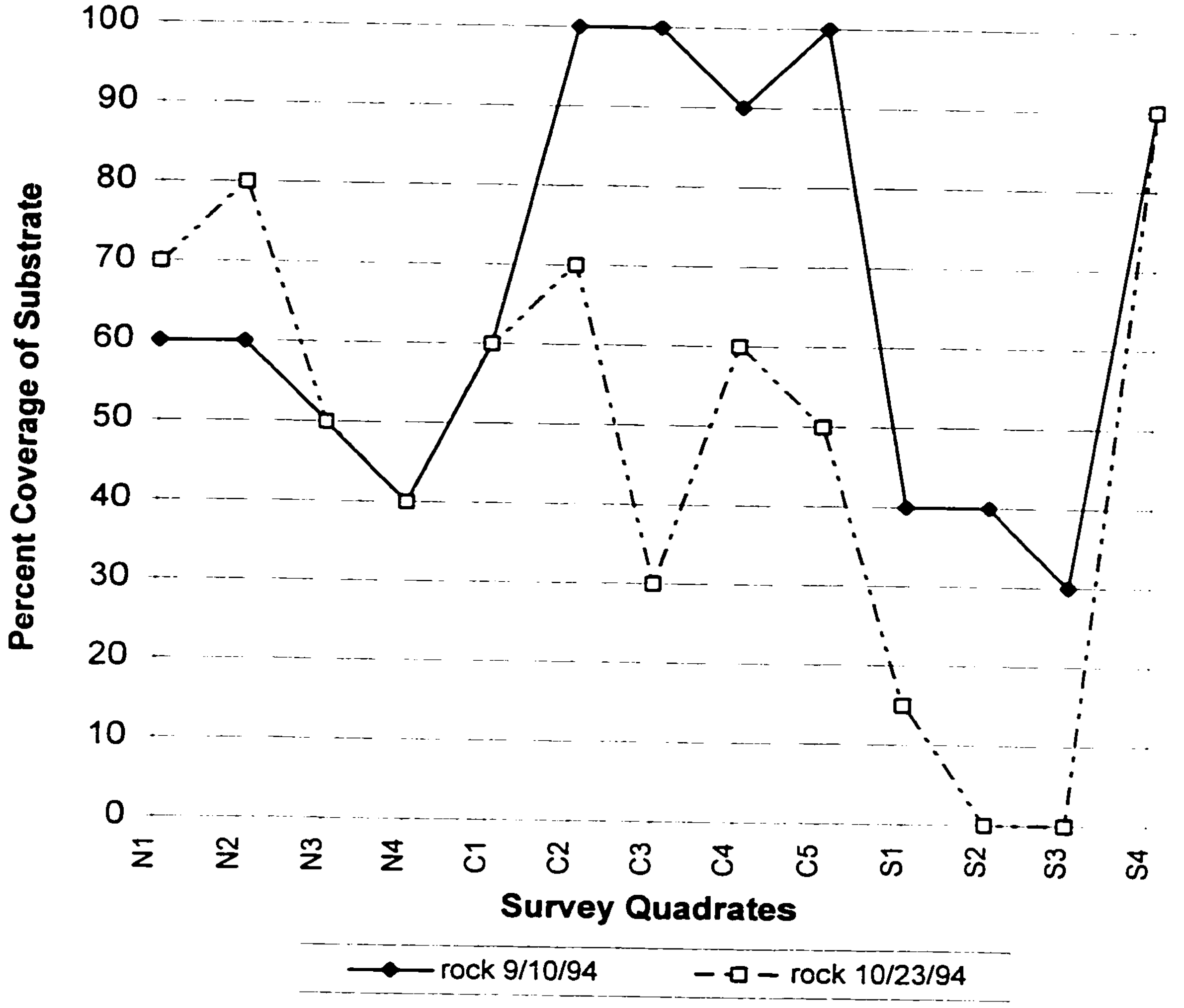


Figure 2.19. Percent coverage by rock substrate (rock) on Boeing Creek Artificial Reef ARH north (N), central (C), and south (S) habitats.

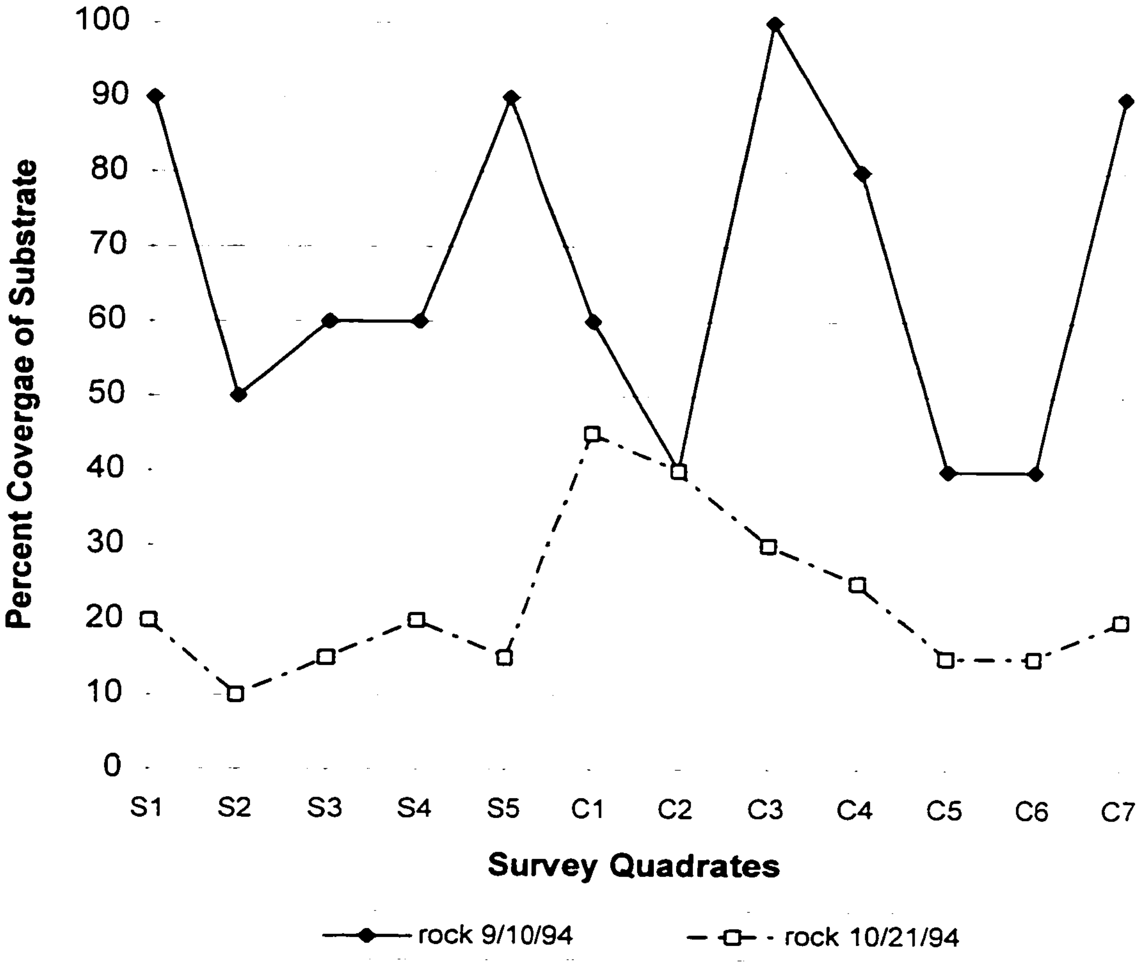


Figure 2.20. Percent coverage by rock substrate (rock) on Boeing Creek Artificial Reef IRH central (C) and south (S) habitats.

the IRH east and base habitats (t-tests, arcsine transformations; $|t| = 5.478$, $p = 0.002$, and $|t| = 7.367$, $p < 0.001$, respectively; Figure 2.21). The east habitat quadrates had the greater average percent coverage of benthic macrophytes on both the ARH and IRH. The average benthic macrophyte coverage was greater on the IRH than the ARH (t-test, arcsine transformation; $|t| = 2.932$, $p = 0.008$).

### 1994 Recruitment to Artificial Reef Habitats

Surveys of the quadrates on BCAR were conducted from August 22, 1994 to May 19, 1995 (c-y d 53 to 323; Appendix IV.A, B), and on GIAR from September 6, 1994 to June 8, 1995 (c-y d 68 to 343; Appendix V.A, B). The first 1994 cohort juvenile rockfish recorded on the reef substrates at BCAR, were quillback rockfish on the IRH central habitat on c-y d 72 (September 10); the first juvenile quillback rockfish recorded on the BCAR ARH reef substrates, were on the central habitat on c-y d 115 (October 23). Surveys of the BCAR ARH and IRH base habitats first recorded juvenile quillback rockfish on c-y d 121 (October 29). Recruitment of 1994 cohort copper rockfish was minimal on BCAR; the only juvenile was recorded on c-y d 323 (May 19) on the ARH base habitat. The first 1994 cohort juvenile rockfish recorded on GIAR, were quillback rockfish on the ARH and IRH east and base habitats on c-y d 68 (September 6). No 1994 cohort copper rockfish were recorded on GIAR. The recruitment of 1994 cohort juvenile quillback rockfish to both the ARH and IRH on BCAR and GIAR were somewhat protracted, but single settlement periods; small-sized recruits (40-70 mm TL) were not found in surveys on BCAR after c-y d 115 (Figure 2.22), or in surveys on GIAR after c-y d 116 (Figure 2.23).

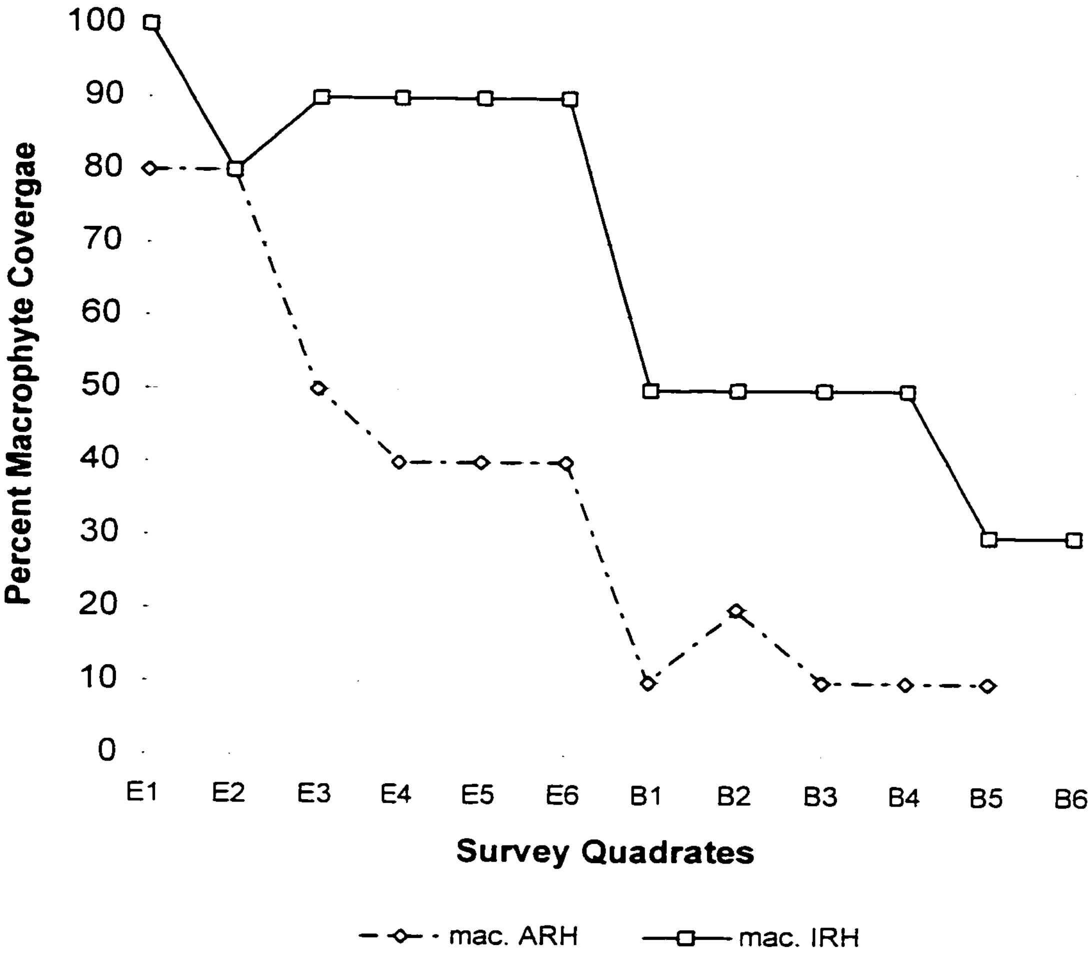
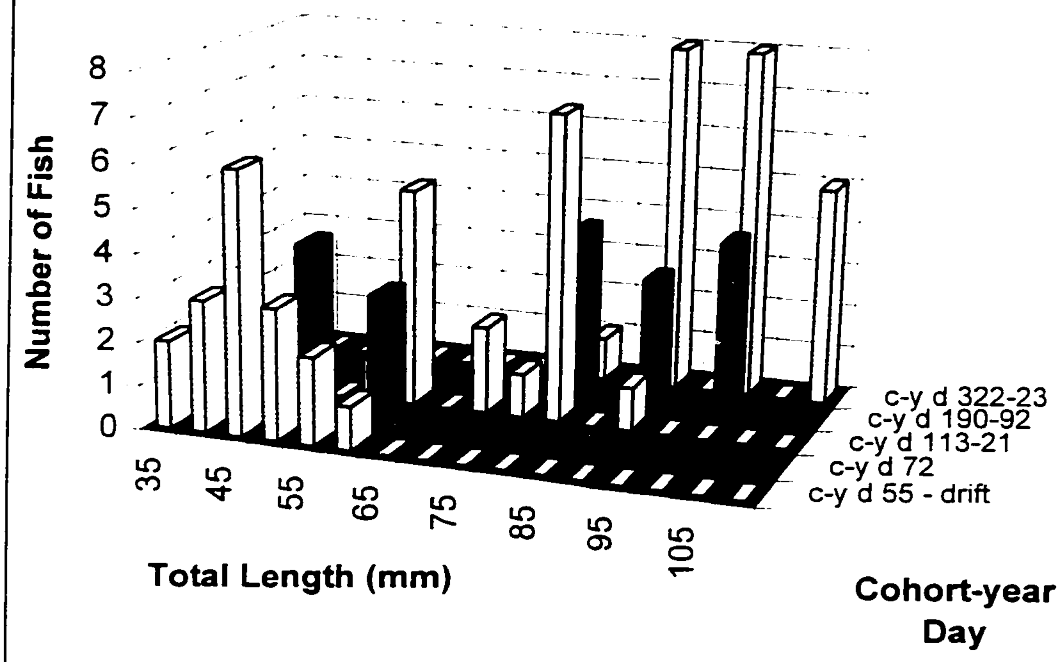


Figure 2.21. Percent macrophyte coverage (mac.) on Gedney Island Artificial Reef ARH and IRH east (E) and base (B) habitats.



Avg. TL ± SD
c-y d 55: 44.8 ± 6.5
c-y d 72: 54.3 ± 5.3
c-y d 113-21: 71.7 ± 10.3
c-y d 190-92: 90 ± 8.5
c-y d 322-23: 97.4 ± 8.6

Figure 2.22. Length frequency distributions of substrate associated 1994 cohort juvenile quillback rockfish on Boeing Creek Artificial Reef ARH and IRH combined.

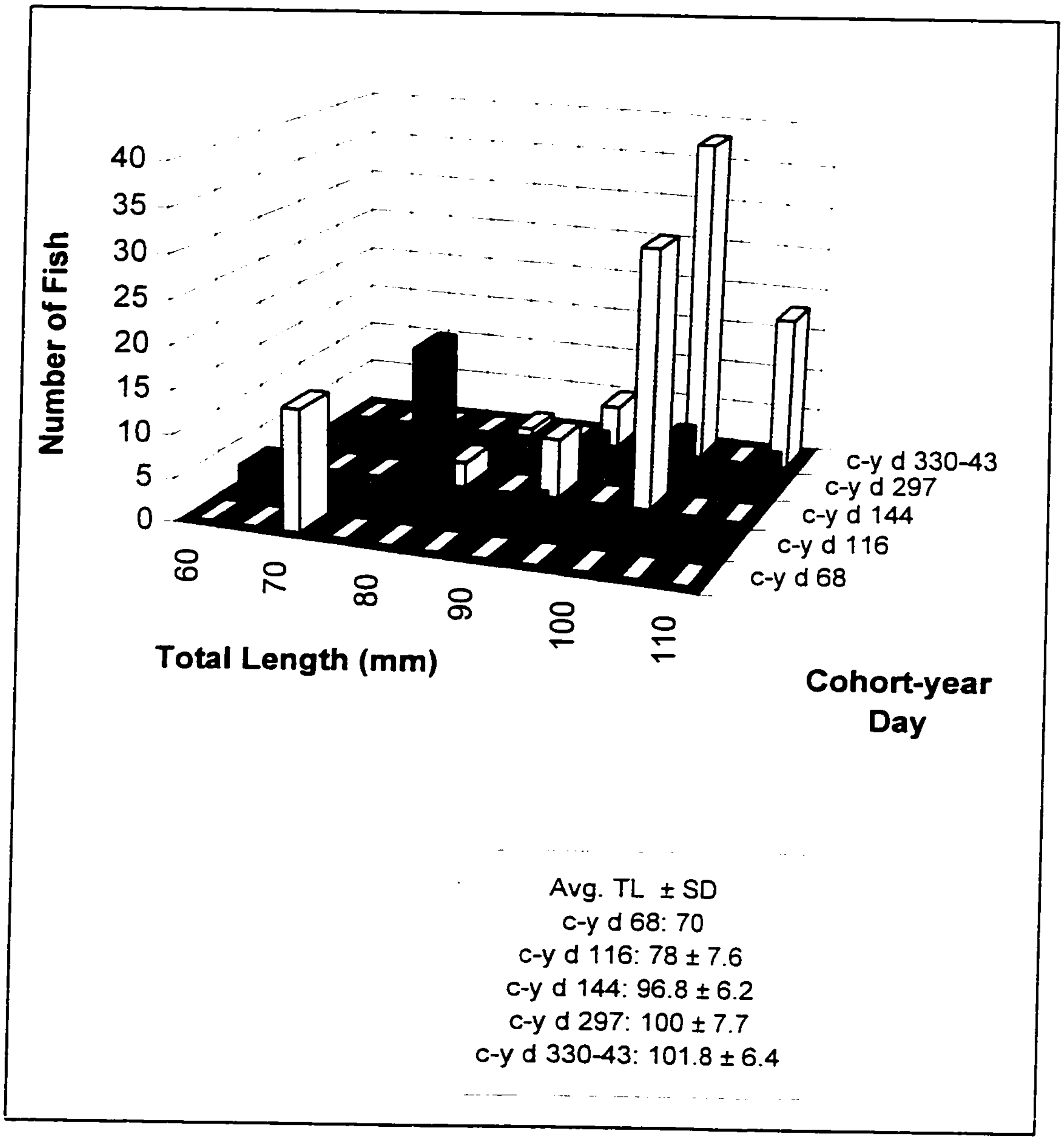


Figure 2.23. Length frequency distributions of substrate associated 1994 cohort juvenile quillback rockfish on Gedney Island Artificial Reef ARH and IRH combined.

The recruitment of 1994 cohort quillback rockfish on BCAR appeared to be low. Surveys of ARH and IRH base habitats over the cohort-year found juvenile rockfish in only 27% of the 66 quadrates surveyed (Table 2.9); when juveniles were present in the quadrate surveys, the average was only 2.3 fish quadrate$^{-1}$ on the ARH, and 1.8 fish quadrate$^{-1}$ on the IRH (Appendix IV.A, B). The highest number of juveniles surveyed in any BCAR quadrate was 7 in ARH quadrate B6 on c-yd 121, for a quadrate density of 0.583 fish m$^{-2}$.

Juvenile quillback rockfish densities per quadrate were not normally distributed for both the BCAR ARH and IRH (Figure 2.24), showing distinct clustering at 0 fish m$^{-2}$ (ARH - CD = 3.68; IRH - CD = 2.42). The juvenile densities per quadrate for ARH and IRH base habitats were summed across quadrates by c-y d of the surveys, to reduce the number of 0 densities, and give average density estimates to normalize the distribution of the data (Table 2.9). The average densities of juveniles on the ARH were normally distributed (L K-S test; D = 0.285, p = 0.140), but the average densities on the IRH were not normally distributed (L K-S test; D = 0.413, p = 0.002), although the variances of the densities of the juveniles on the ARH and IRH were homogeneous (L test; F = 0.210, p = 0.657). The disproportionately high densities of juvenile quillback rockfish on the IRH base habitat during the survey on c-y d 322 caused the non-normal distribution of the IRH average densities (Table 2.9; Figure 2.25); with this survey data removed, the average densities on the IRH were normally distributed (L K-S test; D = 0.300, p = 0.161), however the variances of the densities on the ARH and IRH were no longer homogeneous (L test; F = 9.882, p = 0.012).

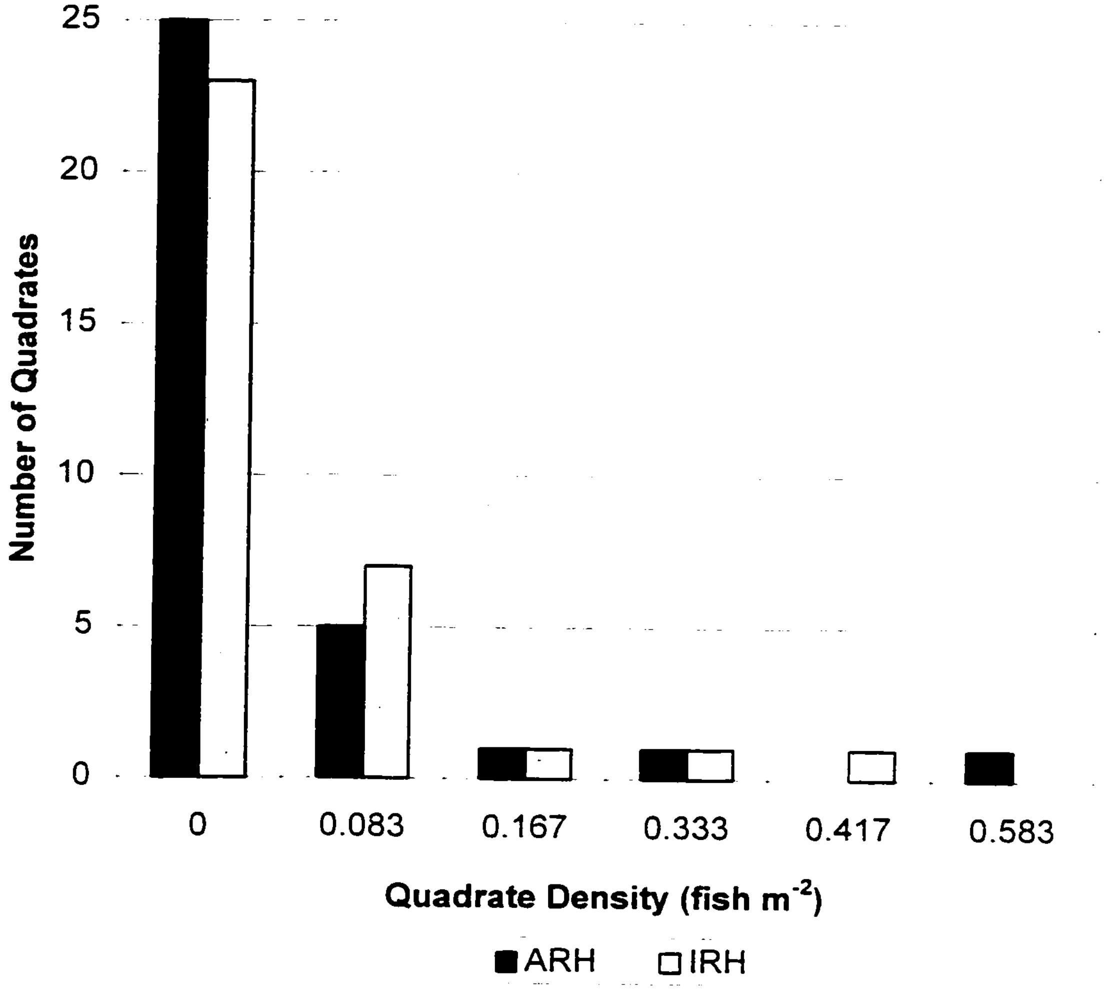


Figure 2.24. Distribution of Boeing Creek Artificial Reef ARH and IRH survey quadrates by density of 1994 cohort juvenile quillback rockfish.

Table 2.9. Densities of 1994 cohort juvenile quillback rockfish in Boeing Creek Artificial Reef ARH and IRH survey quadrates.

Adjacent Recruitment Habitat (ARH) Quadrate Densitiy[1]

| c-y d[2] | B1 | B2 | B3 | B4 | B5 | B6 | verage |
|---|---|---|---|---|---|---|---|
| 72 | 0 | 0 | 0 | | | | 0 |
| 121 | 0.083 | 0 | 0 | 0 | 0 | 0.583 | 0.111 |
| 135 | 0.083 | 0 | 0 | 0.083 | 0 | 0.333 | 0.083 |
| 192 | 0 | 0 | 0.083 | 0 | 0 | 0.083 | 0.028 |
| 270 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 323 | 0 | 0 | 0 | 0 | 0 | 0.167 | 0.028 |

Isolated Recruitment Habitat (IRH) Quadrate Densitiy[1]

| c-y d[2] | B1 | B2 | B3 | B4 | B5 | B6 | verage |
|---|---|---|---|---|---|---|---|
| 54 | 0 | 0 | 0 | | | | 0 |
| 121 | 0.083 | 0 | 0 | 0 | 0 | 0 | 0.014 |
| 134 | 0.083 | 0 | 0 | 0 | 0 | 0 | 0.014 |
| 190 | 0 | 0.083 | 0.083 | 0 | 0 | 0 | 0.028 |
| 272 | 0 | 0 | 0 | 0 | 0.083 | 0 | 0.014 |
| 322 | 0.083 | 0.417 | 0.333 | 0.167 | 0.083 | 0 | 0.181 |

[1] B = base habitat quadrate; juvenile rockfish $m^{-2}$.

[2] c-y d = cohort-year day; see Table 2.3.

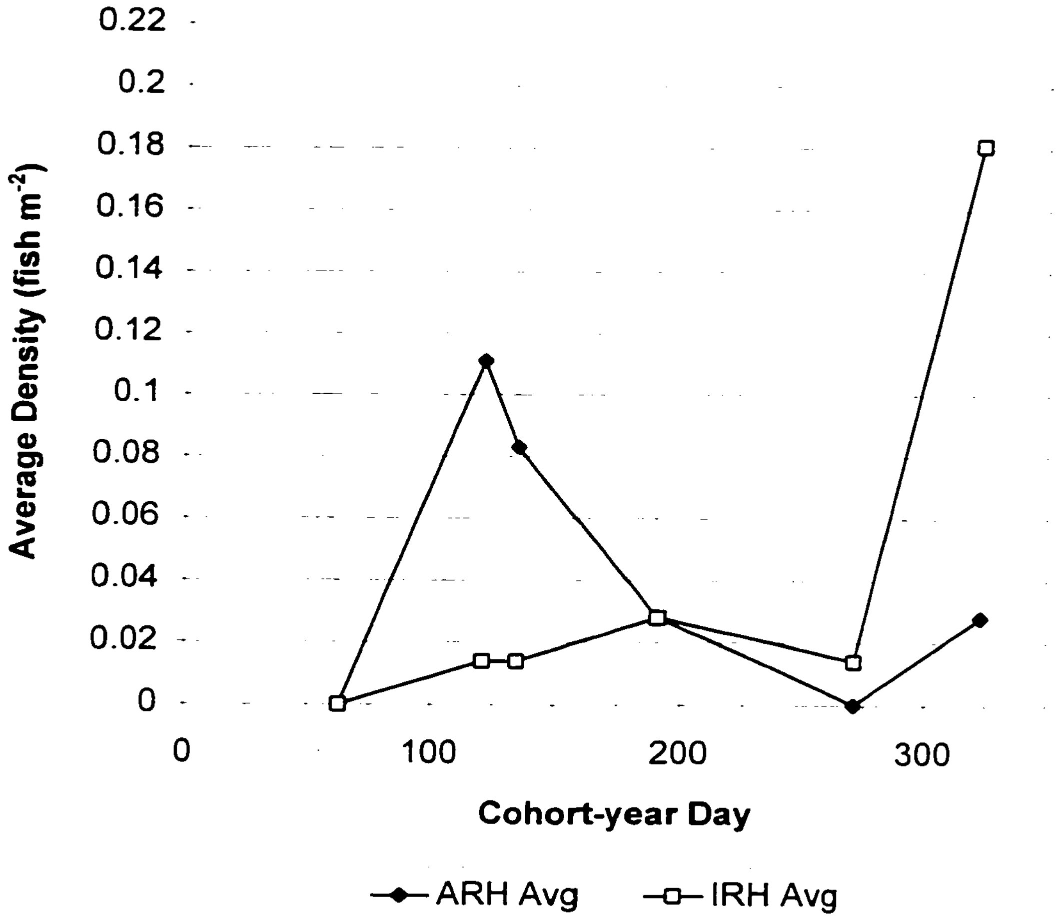


Figure 2.25. Average densities of substrate associated 1994 cohort juvenile quillback rockfish on Boeing Creek Artificial Reef ARH and IRH.

The average densities of 1994 cohort juvenile quillback rockfish on BCAR ARH and IRH (Figure 2.25) demonstrated patterns similar to the temporally decreasing (starting in January) and then increasing (starting in April) densities of the tagged 1991 cohort juveniles on BCAR (see 1991 Tagging on Boeing Creek Artificial Reef). This pattern is clearest for average juvenile densities on the ARH; the irregularity of the average densities on the IRH for earlier c-y d were probably artifacts of variable detectability of the juveniles at extremely low levels of recruitment. The high average density of juvenile rockfish from the IRH base habitat survey on c-y d 322 was included in the comparison of densities on the ARH and IRH, as this was an accurate estimate (i.e., 3 of the 6 quadrates had unusually high densities of juveniles; Table 2.9), and not an outlier. The non-normal distribution of the juvenile densities on the IRH caused by these survey data violates the Analysis of Variance assumption of data normality, however Analysis of Variance is robust to violations of this assumption, even with skewed distributions (Zar 1984). There were no significant differences in the average densities of juvenile quillback rockfish on BCAR ARH and IRH base habitats over the cohort-year (F-test; $F = 0.000$, $p = 0.996$).

The recruitment of 1994 cohort juvenile quillback rockfish to GIAR also appeared to be low. Surveys of ARH and IRH east and base habitats over the cohort-year found juvenile rockfish in only 34% of the 138 quadrates surveyed (Table 2.10); when juveniles were present in the quadrate surveys, the average was only 1.8 fish quadrate$^{-1}$ on both the ARH and IRH east and base habitats combined (Appendix V.A, B). The highest number of juveniles surveyed in any GIAR quadrate was 8 in ARH quadrate B2 on c-y d 330, for a quadrate density of 0.667 fish m$^{-2}$.

Table 2.10. Densities of 1994 cohort juvenile quillback rockfish in Gedney Island Artificial Reef ARH and IRH survey quadrates.

Adjacent Recruitment Habitat (ARH) Quadrate Density[1]

| c-y d[2] | E1 | E2 | E3 | E4 | E5 | E6 | Average |
|---|---|---|---|---|---|---|---|
| 68 | 0 | 0 | 0 | 0.167 | 0.083 | 0 | 0.042 |
| 116 | 0.083 | 0.083 | 0 | 0 | 0 | 0 | 0.028 |
| 143 | 0.083 | 0.083 | 0 | 0.083 | 0 | 0 | 0.042 |
| 205 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 297 | 0 | 0 | 0.083 | 0 | 0 | 0 | 0.014 |
| 330 | 0.167 | 0.167 | 0.083 | 0 | 0.167 | 0.083 | 0.111 |

| c-y d[2] | B1 | B2 | B3 | B4 | B5 | Average |
|---|---|---|---|---|---|---|
| 68 | 0.083 | 0.083 | 0.083 | 0.083 | 0 | 0.066 |
| 116 | 0.167 | 0.083 | 0.083 | 0 | 0.083 | 0.083 |
| 144 | 0.083 | 0 | 0 | 0 | 0 | 0.017 |
| 205 | 0 | 0 | 0 | 0 | 0 | 0 |
| 297 | 0 | 0.083 | 0 | 0 | 0.083 | 0.033 |
| 330 | 0.416 | 0.667 | 0.167 | 0.167 | 0.583 | 0.400 |

Isolated Recruitment Habitat (IRH) Quadrate Density[1]

| c-y d[2] | E1 | E2 | E3 | E4 | E5 | E6 | Average |
|---|---|---|---|---|---|---|---|
| 68 | 0 | 0 | 0 | 0.083 | 0 | 0 | 0.014 |
| 116 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 143 | 0 | 0 | 0 | 0 | 0.083 | 0.083 | 0.028 |
| 205 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 297 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 343 | 0 | 0.333 | 0 | 0 | 0 | 0.333 | 0.111 |

| c-y d[2] | B1 | B2 | B3 | B4 | B5 | B6 | Average |
|---|---|---|---|---|---|---|---|
| 68 | 0.167 | 0.083 |  | 0.083 | 0 | 0.083 | 0.083 |
| 116 | 0 | 0.167 | 0 | 0.25 | 0.083 | 0.083 | 0.097 |
| 143 | 0.083 | 0 | 0 | 0.167 | 0 | 0 | 0.042 |
| 205 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 297 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 343 | 0.25 | 0.167 | 0 | 0 | 0 | 0.167 | 0.097 |

[1] E = east and B = base habitat quadrate; juvenile rockfish $m^{-2}$.

[2] c-y d = cohort-year day; see Table 2.3.

Juvenile quillback rockfish densities per quadrate were not normally distributed for the GIAR ARH east and base habitats (Figure 2.26), or the GIAR IRH east and base habitats (Figure 2.27), showing a Poisson distribution on the ARH east habitat (CD = 1.027), and distinct clustering at 0 fish m$^{-2}$ on the ARH base and IRH east and base habitats (CD = 3.356, CD = 2.958, and CD = 1.412, respectively). The juvenile densities per quadrate were summed across quadrates by c-y d of the surveys, to reduce the number of 0 densities, and give average density estimates to normalize the distributions of the data (Table 2.10). The average densities of juveniles on the ARH east habitat and the IRH east and base habitats were normally distributed (L K-S tests; D = 0.308, p = 0.079, D = 0.310, p = 0.073, and D = 0.179, p > 0.200, respectively), but the average densities on the ARH base habitat were not normally distributed (L K-S test; D = 0.378, p = 0.008), although the variances of the densities of juveniles on all of these habitats were homogeneous (L test; F = 2.354, p = 0.103). The disproportionately high densities of juvenile quillback rockfish on the ARH base habitat during the survey on c-y d 330 caused the non-normal distribution of the ARH base habitat average densities (Table 2.10; Figure 2.28); with this survey data removed, the average densities on the ARH base habitat were normally distributed (L K-S test; D = 0.210, p > 0.200), and the variances of the densities of juveniles on all of the habitats remained homogeneous (L test; F = 0.411, p = 0.747).

The average densities of 1994 cohort juvenile quillback rockfish on GIAR ARH and IRH east and base habitats also demonstrated the pattern of temporally decreasing and then increasing densities found on BCAR (Figures 2.28 and 2.29). The period of reduced densities (i.e., reduced detectability in the visual

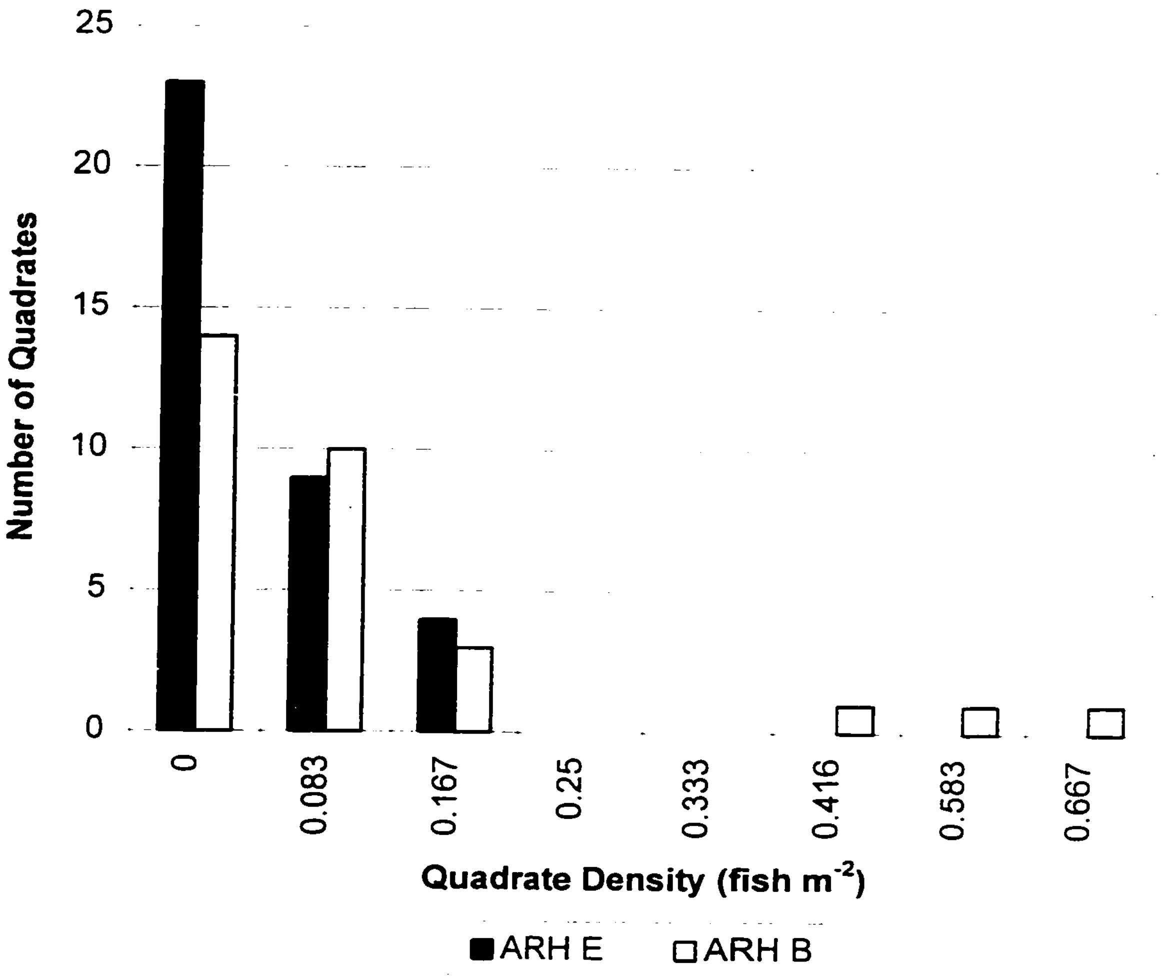


Figure 2.26. Distribution of Gedney Island Artificial Reef ARH east (E) and base (B) habitats survey quadrates by density of 1994 cohort juvenile quillback rockfish.

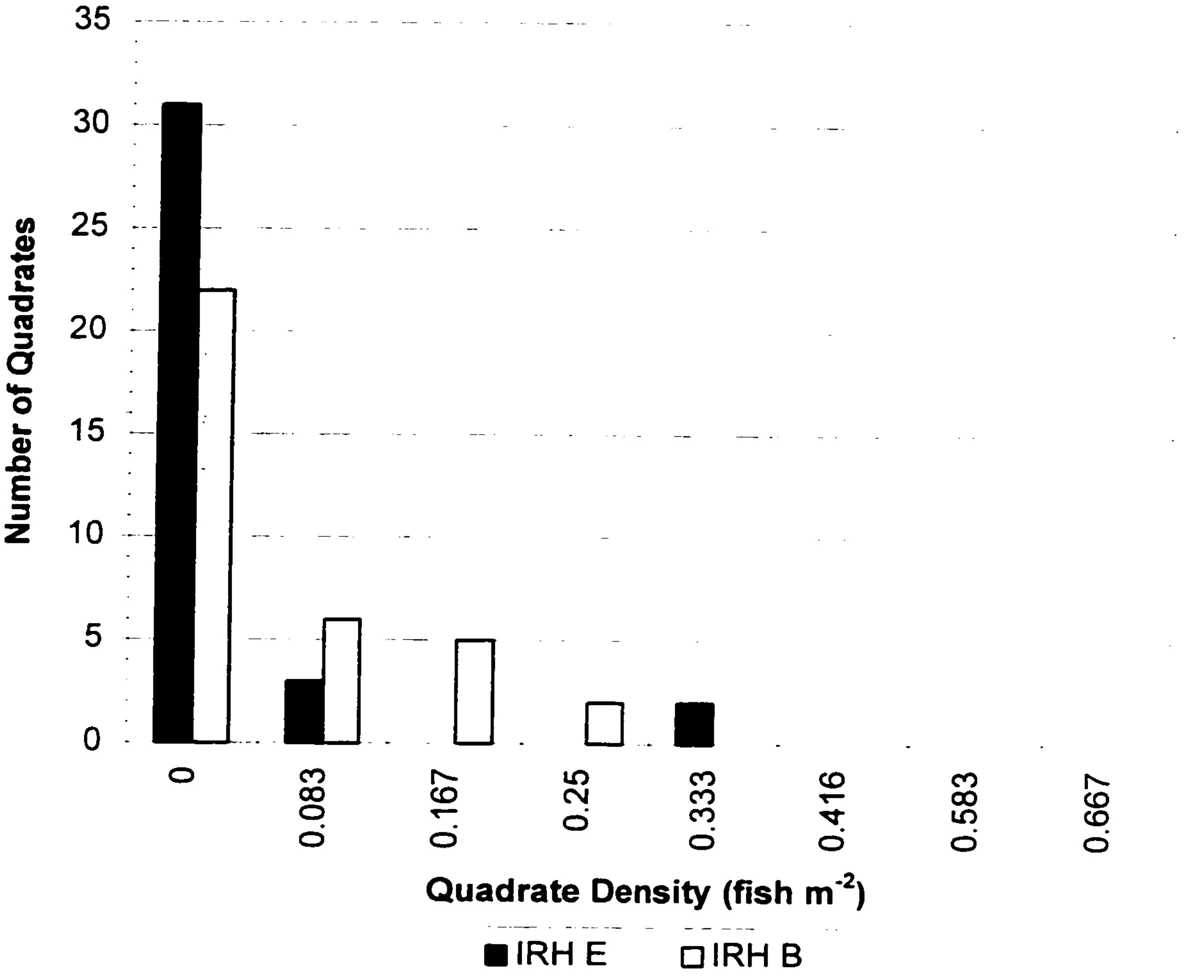


Figure 2.27. Distribution of Gedney Island Artificial Reef IRH east (E) and base (B) habitats survey quadrates by density of 1994 cohort juvenile quillback rockfish.

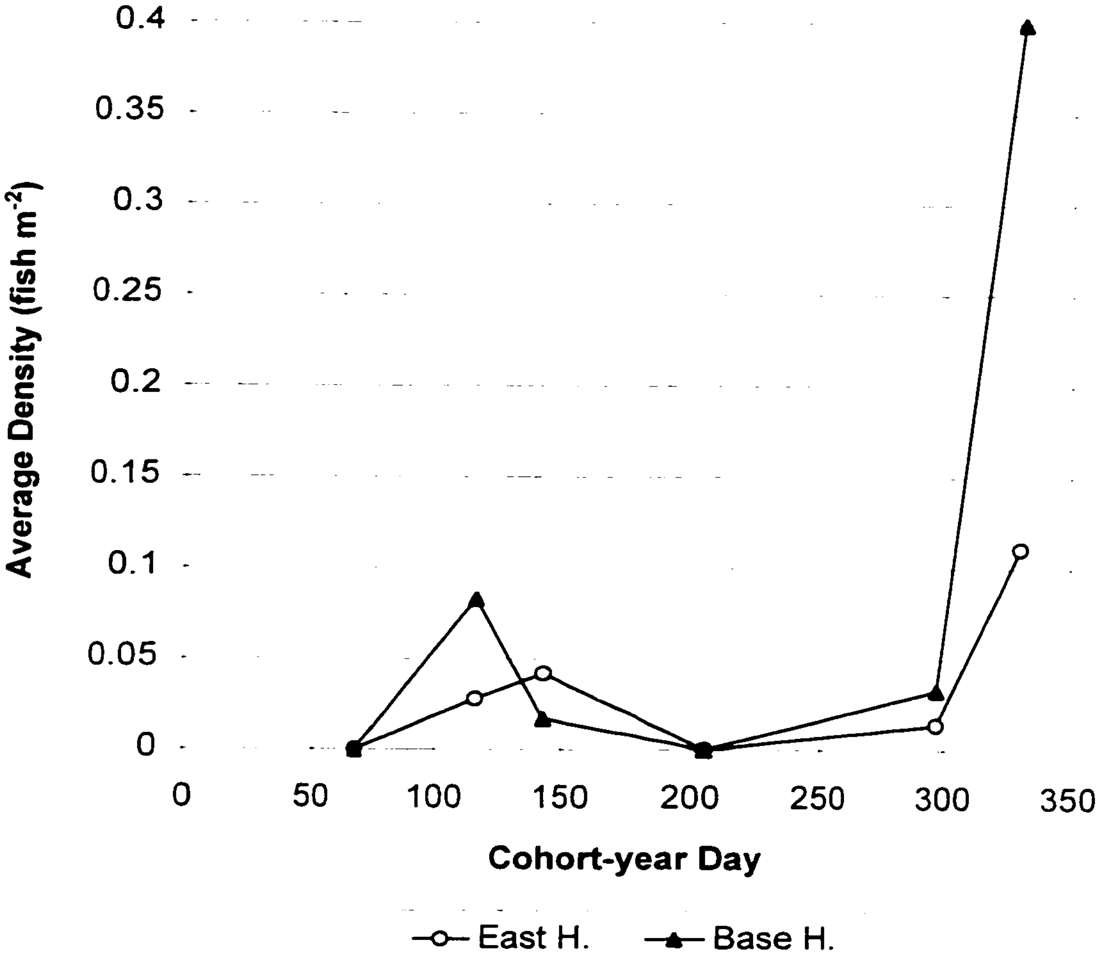


Figure 2.28. Average densities of substrate associated 1994 cohort juvenile quillback rockfish on Gedney Island Artificial Reef ARH east and base habitats.

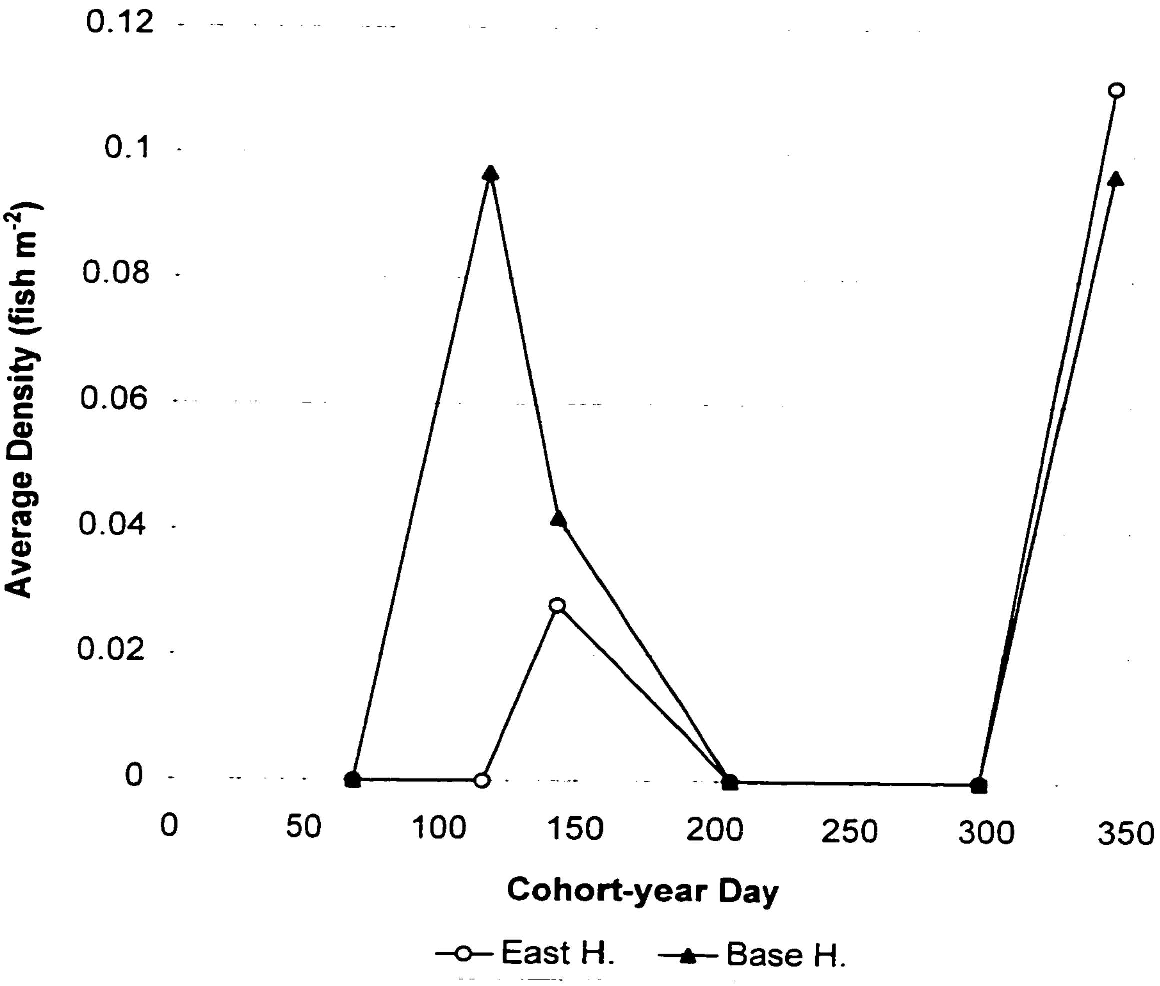


Figure 2.29. Average densities of substrate associated 1994 cohort juvenile quillback rockfish on Gedney Island Artificial Reef IRH east and base habitats.

surveys of the quadrates) was also approximately January through April (c-y d 185 to 304), with virtually the same temporal patterns of average juvenile densities on the ARH and IRH (Figure 2.30). The high average density of juvenile rockfish from the GIAR ARH base habitat survey on c-y d 330 was included in the comparisons of densities on the ARH and IRH, as this was an accurate estimate (i.e., 3 of the 5 quadrates had unusually high densities of juveniles; Table 2.10), and not an outlier; again, the robustness of Analysis of Variance to non-normality was considered adequate justification (Zar 1984). There were no significant differences in the average densities of juvenile quillback rockfish over the cohort-year on the GIAR ARH east and base habitats (F-test; $F = 0.915$, $p = 0.361$) and on the GIAR IRH east and base habitats (F-test; $F = 1.162$, $p = 0.306$), or between the ARH and IRH with east and base habitats combined (F-test; $F = 0.788$, $p = 0.384$). For the last survey period (c-y d 330-343) when the densities of juvenile quillback rockfish were the highest on GIAR (Figures 2.28 and 2.29), the average densities on the ARH and IRH east and base habitats were not equal (ANOVA; $F = 4.795$, $p = 0.012$); the density of juveniles on the ARH base habitat (0.4 fish $m^{-2}$) was significantly higher than on the other habitats (Tukey-HSD test, $\alpha = 0.05$).

Juvenile quillback rockfish were found on the BCAR original artificial reef habitat adjacent to the ARH only during the survey on c-y d 323 (average 0.042 fish $m^{-2}$; Appendix IV.A). There was no apparent difference in the average densities of juvenile quillback rockfish on the base habitat (average 0.028 fish $m^{-2}$) and original reef habitat for this survey. Juvenile quillback rockfish from the 1994 cohort were not found on the original artificial reef habitat at GIAR (Appendix V.A).

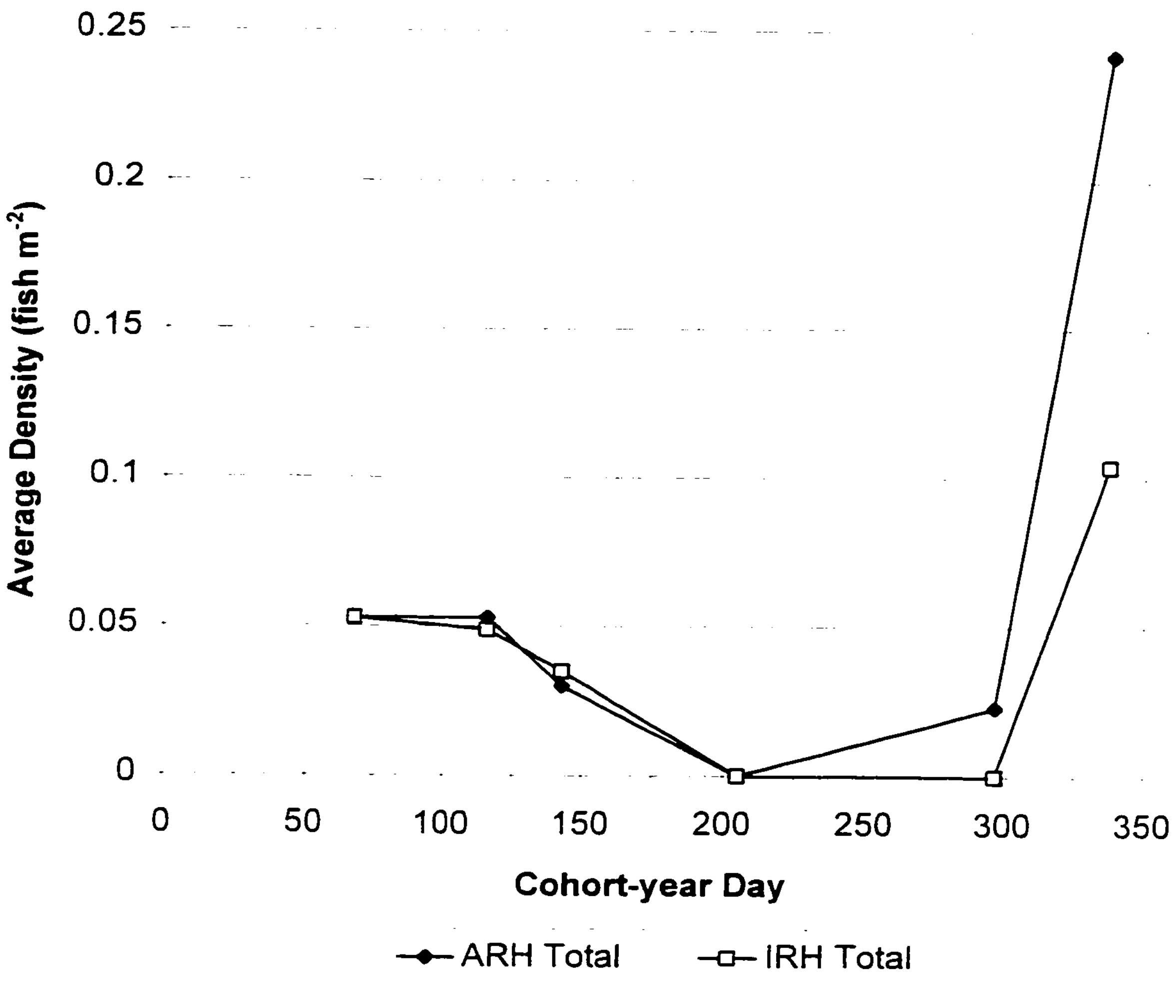


Figure 2.30. Average densities of substrate associated 1994 cohort juvenile quillback rockfish on Gedney Island Artificial Reef ARH and IRH.

### 1994 Cohort-year Adult *Sebastes* on Artificial Reefs

Quillback rockfish and copper rockfish from previous cohorts (i.e., sub-adults and adults) were included in the surveys of the BCAR ARH and IRH base habitats, and the original artificial reef, during c-y d 121 to 323 (Appendix IV.A, B). Copper rockfish were found only on the IRH, and at significantly lower densities than quillback rockfish (paired t-test; $|t| = 7.240$, $p = 0.002$; Table 2.11). Densities of quillback rockfish were significantly different on the ARH, IRH, and original artificial reef (ANOVA; $F = 33.721$, $p < 0.001$); densities on the IRH were significantly higher than on the other habitats (Tukey-HSD test, $\alpha = 0.05$). The densities of rockfishes from previous cohorts on the BCAR ARH, IRH, and original artificial reef, followed the same temporally decreasing and then increasing pattern that was found for the 1994 cohort juvenile rockfishes on BCAR (Figure 2.31).

Quillback rockfish and copper rockfish from previous cohorts were included in the surveys of the GIAR ARH, IRH, and original artificial reef during c-y d 68 to 337 (Appendix V.A, B). Copper rockfish were found on all three habitats, but densities were significantly different (ANOVA; $F = 77.871$, $p < 0.001$); copper rockfish densities were higher on the original artificial reef than on the ARH and IRH (Tukey-HSD test, $\alpha = 0.05$; Table 2.11.). Densities of quillback rockfish were not significantly different on the ARH, IRH, and original artificial reef (ANOVA; $F = 1.258$, $p = 0.314$). Densities of quillback rockfish and copper rockfish combined were significantly different on the three habitats (ANOVA; $F = 6.860$, $p = 0.008$); again, densities were higher on the original artificial reef than on the ARH and IRH (Tukey-HSD test, $\alpha = 0.05$). The densities of rockfishes from previous cohorts on the GIAR ARH, IRH, and original artificial reef demonstrated the

Table 2.11. Densities of quillback rockfish and copper rockfish from previous cohorts on Boeing Creek Artificial Reef (BCAR) and Gedney Island Artificial Reef (GIAR) ARH and IRH, and original artificial reef, during the 1994 cohort-yaer.

BCAR

| | ARH Quadrate[1] | | | IRH Quadrate[1] | | | Original Reef Quadrate[1] | | |
|---|---|---|---|---|---|---|---|---|---|
| c-y d[2] | Cr | Qb | Total | Cr | Qb | Total | Cr | Qb | Total |
| 121 | 0 | 0.111 | 0.111 | 0 | 1.639 | 1.639 | 0 | 0.542 | 0.542 |
| 135 | 0 | 0.097 | 0.097 | 0.028 | 1.556 | 1.584 | 0 | 0.417 | 0.417 |
| 192 | 0 | 0.042 | 0.042 | 0 | 1 | 1 | 0 | 0.083 | 0.083 |
| 270 | 0 | 0.014 | 0.014 | 0.042 | 1.111 | 1.153 | 0 | 0.021 | 0.021 |
| 323 | 0 | 0.111 | 0.111 | 0.014 | 2.125 | 2.139 | 0 | 0.396 | 0.396 |

GIAR

| | ARH Quadrate[1] | | | IRH Quadrate[1] | | | Original Reef Quadrate[3] | | |
|---|---|---|---|---|---|---|---|---|---|
| c-y d[2] | Cr | Qb | Total | Cr | Qb | Total | Cr | Qb | Total |
| 68 | 0.152 | 2.084 | 2.236 | 0.114 | 1.045 | 1.159 | | | |
| 116 | 0.045 | 0.364 | 0.409 | 0.014 | 0.09 | 0.104 | 0.958 | 0.876 | 1.833 |
| 143 | 0.023 | 0.379 | 0.402 | 0.007 | 0.208 | 0.215 | 0.889 | 0.806 | 1.695 |
| 205 | 0.03 | 0.053 | 0.083 | 0 | 0.007 | 0.007 | 0.458 | 0.5 | 0.958 |
| 297 | 0 | 0.16 | 0.16 | 0 | 0.007 | 0.007 | 0.917 | 1 | 1.917 |
| 337 | 0.068 | 0.546 | 0.614 | 0.042 | 0.708 | 0.75 | 0.833 | 1.083 | 1.916 |

1] See List of Abbreviations; Cr = copper rockfish; Qb = quillback rockfish; rockfish $m^{-2}$.

2] c-y d = cohort-year day; see Table 2.3.

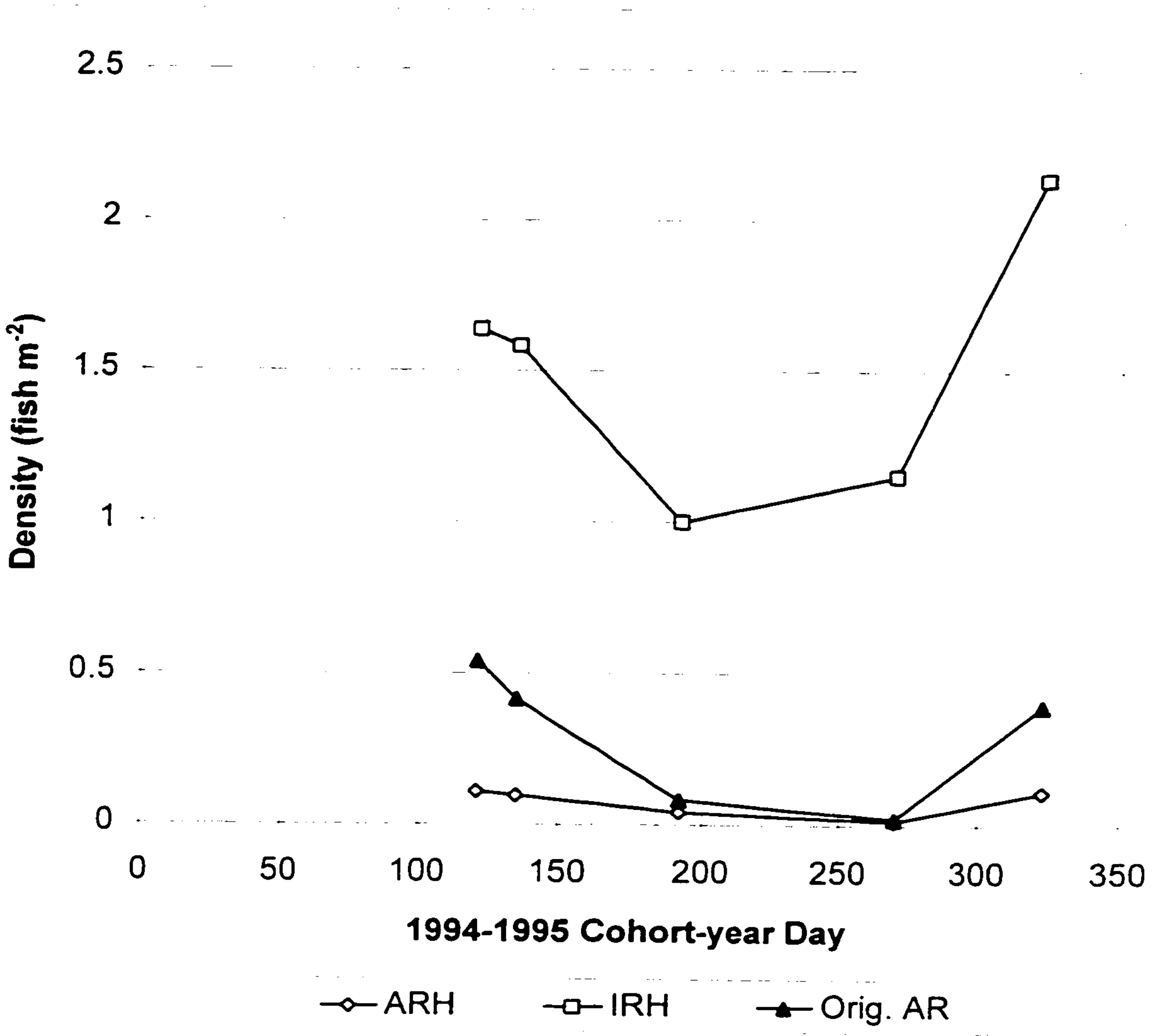


Figure 2.31. Average densities of quillback rockfish and copper rockfish from previous cohorts on Boeing Creek Artificial Reef ARH, IRH, and original artificial reef (Orig. AR), during the 1994-1995 cohort-year.

same temporally decreasing and then increasing pattern that was noted for densities of 1994 cohort juvenile rockfishes on the GIAR ARH and IRH habitats (Figure 2.32).

### 1994 Cohort Habitat Use Models

Recruitment of juvenile quillback rockfish to the central and south habitats of BCAR IRH, as part of the substrate associated recruitment process, occurred through c-y d 113 (see 1994 Recruitment to Artificial Reef Habitats). The habitat parameters examined in the survey quadrates during this recruitment period were the numbers of bull kelp stipes in the quadrates ($X_1$), the percentages of the quadrate areas that were rock habitat (i.e., refuge substrate; $X_2$), the depths of the quadrates (below MLLW; $X_3$), and the percentages of the quadrate areas that were covered by benthic macrophytes ($X_4$; Appendix III). *Sebastes* from previous cohorts (i.e., sub-adults and adults) were virtually absent on the central and south habitats during the recruitment of juvenile quillback rockfish; only one quillback rockfish from a previous cohort was found on the central habitat on c-y d 72.

These habitat parameters from the surveys on c-y d 72 and 113 were used in a linear regression model to determine their affects on juvenile quillback rockfish densities (Y) in the quadrates of BCAR IRH central and south habitats. The rock habitat area in the quadrates ($X_2$), and the benthic macrophyte coverage of the quadrates ($X_4$) , were significantly positively correlated with juvenile quillback rockfish densities (CC; $r = 0.560$, $p = 0.016$, and $r = 0.742$, $p < 0.001$, respectively), and the depths of the quadrates ($X_3$) were significantly negatively correlated with juvenile quillback rockfish densities (CC; $r = -0.580$, $p = 0.012$). The number of bull kelp stipes in the quadrates ($X_1$) was positively correlated

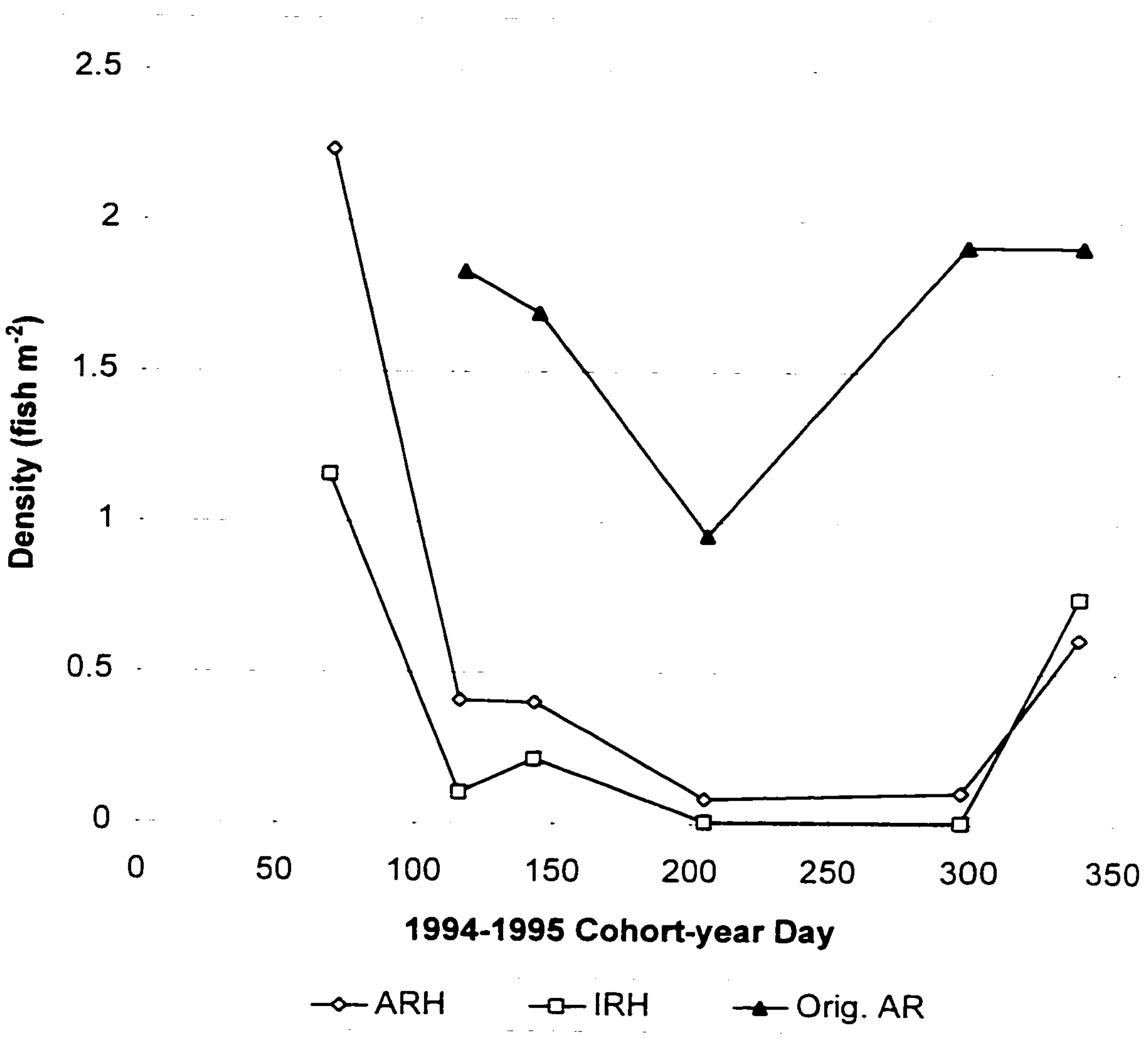


Figure 2.32. Average densities of quillback rockfish and copper rockfish from previous cohorts on Gedney Island Artificial Reef ARH, IRH, and original artificial reef (Orig. AR), during the 1994-1995 cohort-year.

with juvenile quillback rockfish densities, but not significantly (CC; $r = 0.439$, $p = 0.068$). Visual interpretations of the patterns of residuals from first order models using these independent variables, plotted against the possible interaction terms for the variables, did not indicate interactions between these variables in the regression model (see Data Analyses Methods), and they were considered to have additive effects.

Habitat selection and use by juvenile quillback rockfish on the IRH central and south habitats of BCAR during early substrate associated recruitment, was best described by the following regression model, which gave the highest $R^2_a$ value (Table 2.12; Figure 2.33):

$$Y = -0.0257 - 0.0020 X_1 + 0.0010 X_2 + 0.0025 X_4$$

where:

$Y$ = density of juvenile quillback rockfish

$X_1$ = number of bull kelp stipes

$X_2$ = area of rock habitat

$X_4$ = coverage by benthic macrophytes.

There was a significant linear relationship between the density of juvenile quillback rockfish and these habitat parameters (ANOVA; $F = 11.957$, $p < 0.001$).

Meaningful assessments of habitat use by juvenile quillback rockfish were not possible on the ARH north, central, and south habitats of BCAR, due to insufficient recruitment of juveniles during c-y d 72 and 115 (i.e., only one recruit on c-y d 115). Meaningful assessments were also not possible on the ARH and IRH base habitats for c-y d 121-272, due to patterns of temporally decreasing and then increasing densities (i.e., variable exposure to visual surveys) of juvenile quillback rockfish during this period (see 1994 Recruitment to Artificial

Table 2.12. Habitat use models for 1994 cohort juvenile quillback rockfish densities[1] on Boeing Creek Artificial Reef IRH during the early substrate associated recruitment period (c-y d[2] 72-113).

First Order Linear Regression Model with ANOVA

| Variables[3] | Parameters[4] | df[5] | $R^2$ [6] | $R^2_a$ [7] | MSE[8] |
|---|---|---|---|---|---|
| $X_1$ | 2 | 16 | 0.1926 | 0.1421 | 0.00149 |
| $X_2$ | 2 | 16 | 0.314 | 0.2711 | 0.00126 |
| $X_3$ | 2 | 16 | 0.3359 | 0.2944 | 0.00122 |
| $X_4$ | 2 | 16 | 0.5508 | 0.5227 | 0.00083 |
| $X_1$, $X_2$ | 3 | 15 | 0.3263 | 0.2365 | 0.00132 |
| $X_1$, $X_3$ | 3 | 15 | 0.351 | 0.2644 | 0.00128 |
| $X_1$, $X_4$ | 3 | 15 | 0.6163 | 0.5651 | 0.00075 |
| $X_2$, $X_3$ | 3 | 15 | 0.5127 | 0.4477 | 0.00096 |
| $X_2$, $X_4$ | 3 | 15 | 0.5881 | 0.5331 | 0.00081 |
| $X_3$, $X_4$ | 3 | 15 | 0.5519 | 0.4922 | 0.00088 |
| $X_1$, $X_2$, $X_3$ | 4 | 14 | 0.5401 | 0.4415 | 0.00097 |
| $X_1$, $X_2$, $X_4$ | 4 | 14 | 0.7193 | 0.6591 | 0.00059 |
| $X_1$, $X_3$, $X_4$ | 4 | 14 | 0.6168 | 0.5347 | 0.00081 |
| $X_2$, $X_3$, $X_4$ | 4 | 14 | 0.5948 | 0.508 | 0.00085 |
| $X_1$, $X_2$, $X_3$, $X_4$ | 5 | 13 | 0.7306 | 0.6477 | 0.00061 |

[1] Juvenile rockfish $m^{-2}$.

[2] c-y d = cohort-year day; see Table 2.3.

[3] Variables in the model; $X_1$ = number of kelp stipes per quadrate; $X_2$ = % rock coverage per quadrate; $X_3$ = quadrate depth (MLLW); $X_4$ = % macrophyte coverage per quadrate.

[4] Parameters in the model.

[5] df = ANOVA degrees of freedom.

[6] $R^2$ = multiple correlation coefficient of the model.

[7] $R^2_a$ = multiple correlation coefficient of the model, adjusted for the number of varialbes in the model.

[8] MSE = ANOVA mean square error.

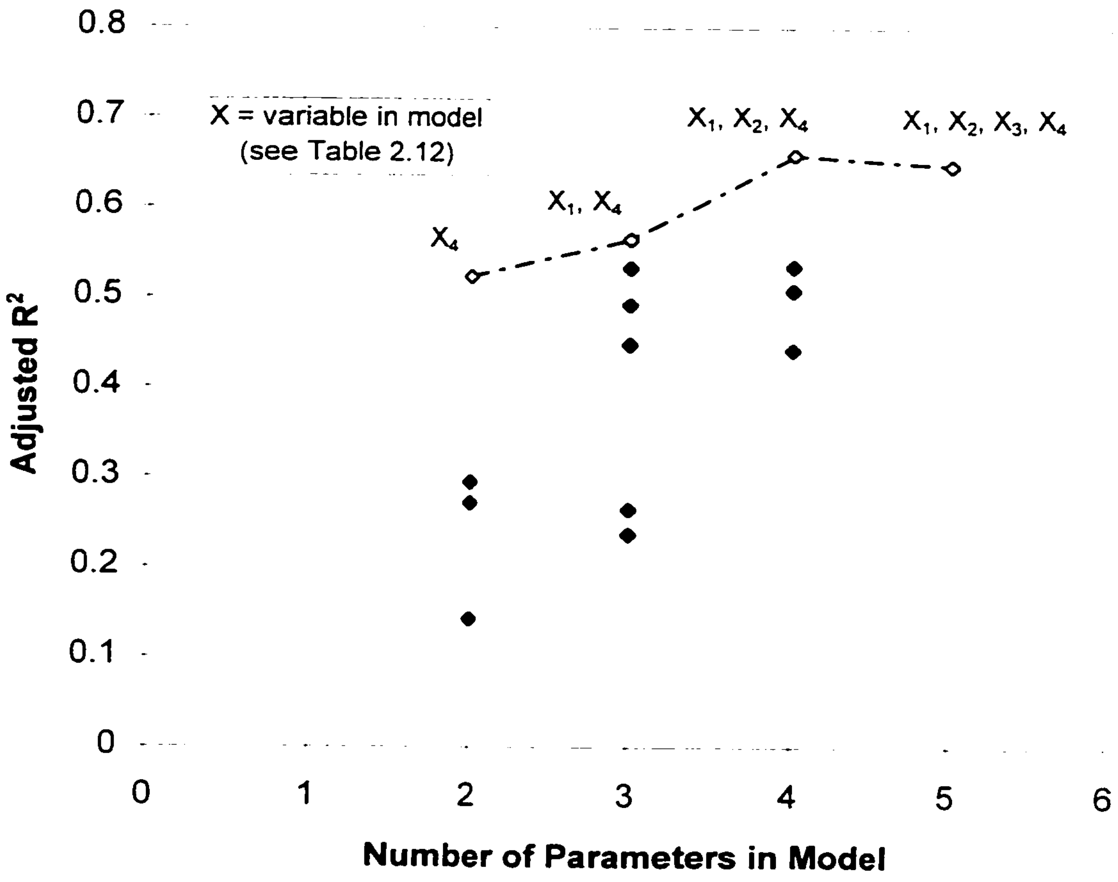


Figure 2.33. Adjusted $R^2$ values of the habitat use models for 1994 cohort juvenile quillback rockfish on Boeing Creek Artificial Reef IRH during c-y d 72-113.

Reef Habitats). Juvenile quillback rockfish habitat use during c-y d 323 on BCAR ARH base habitat also could not be assessed due to low numbers of juveniles (only two juveniles in one quadrate; Appendix IV.A).

Juvenile quillback rockfish surveyed on c-y d 322 on BCAR IRH base habitat appeared to be fully exposed to visual survey techniques, however, all of the IRH base habitat quadrates were at the same depth, and there were no macrophytes on the base habitat. Densities of juvenile quillback rockfish in the survey quadrates were negatively correlated with the rugosity values of the quadrates, and positively correlated with the densities of *Sebastes* from previous cohorts in the quadrates, but neither of these correlations was significant (CC; $r = -0.782$, $p = 0.066$, and $r = 0.300$, $p = 0.583$, respectively). There was no significant linear relationship between the densities of juvenile quillback rockfish and these habitat parameters (ANOVA; $F = 3.808$, $p = 0.150$).

Recruitment of juvenile quillback rockfish to GIAR ARH and IRH east and base habitats, as part of the substrate associated recruitment process, occurred through c-y d 116 (see 1994 Recruitment to Artificial Reef Habitats). The habitat parameters examined in the survey quadrates during this recruitment period were the substrate rugosity values ($X_1$), the densities of *Sebastes* from previous years cohorts ($X_2$), the percentages of the quadrate areas that were covered by benthic macrophytes ($X_3$), and the depths of the quadrates ($X_4$; below MLLW; Appendix III and V.A, B). The affects of these habitat variables on juvenile quillback rockfish densities ($Y$) in the quadrates, during the c-y d 68-116 recruitment period, were examined in linear regression models for the ARH and IRH.

On GIAR IRH during c-y d 68-116, the depth of the quadrates ($X_4$) was significantly positively correlated with juvenile quillback rockfish densities (CC; r = 0.676, p = 0.016); the quadrate rugosity values ($X_1$) and the densities of *Sebastes* from previous cohorts ($X_2$) were also positively correlated with juvenile densities, but not significantly (CC; r = 0.099, p = 0.760, and r = 0.426, p = 0.168, respectively). The areas of the quadrates covered by benthic macrophytes ($X_3$) was negatively correlated with juvenile rockfish densities, but not significantly (CC; r = -0.567, p = 0.055). Visual interpretations of the patterns of residuals from first order models using these independent variables, plotted against the possible interaction terms for the variables, did not indicate interactions between these variables in the regression model (see Data Analyses Methods), and they were considered to have additive effects.

Habitat selection and use by juvenile quillback rockfish on GIAR IRH east and base habitats during early substrate associated recruitment, was best described by the following regression model, which gave the highest $R^2_a$ value (Table 2.13; Figure 2.34):

$$Y = - 4.5264 + 0.00002\ X_1 + 0.0707\ X_2 + 0.0047\ X_3 + 0.4125\ X_4$$

where:

$Y$ = density of juvenile quillback rockfish
$X_1$ = substrate rugosity value
$X_2$ = densities of *Sebastes* from previous cohorts
$X_3$ = coverage by benthic macrophytes
$X_4$ = depth of substrate (MLLW).

There was a significant linear relationship between the densities of juvenile quillback rockfish and these habitat parameters (ANOVA; F = 5.372, p = 0.0268).

Table 2.13. Habitat use models for 1994 cohort juvenile quillback rockfish densities[1] on Gedney Island Artificial Reef IRH during the early substrate associated recruitment period (c-y d[2] 68-116).

First Order Linear Regression Model with ANOVA

| Variables[3] | Parameters[4] | df[5] | $R^2$ [6] | $R^2_a$ [7] | MSE[8] |
|---|---|---|---|---|---|
| $X_1$ | 2 | 10 | 0.0098 | -0.0892 | 0.00338 |
| $X_2$ | 2 | 10 | 0.1813 | 0.0995 | 0.0028 |
| $X_3$ | 2 | 10 | 0.3215 | 0.2537 | 0.00232 |
| $X_4$ | 2 | 10 | 0.4575 | 0.4033 | 0.00185 |
| $X_1$, $X_2$ | 3 | 9 | 0.182 | 0.0002 | 0.0031 |
| $X_1$, $X_3$ | 3 | 9 | 0.3219 | 0.1712 | 0.00257 |
| $X_1$, $X_4$ | 3 | 9 | 0.4935 | 0.381 | 0.00192 |
| $X_2$, $X_3$ | 3 | 9 | 0.3606 | 0.2185 | 0.00243 |
| $X_2$, $X_4$ | 3 | 9 | 0.5295 | 0.4249 | 0.00179 |
| $X_3$, $X_4$ | 3 | 9 | 0.4679 | 0.3495 | 0.00202 |
| $X_1$, $X_2$, $X_3$ | 4 | 8 | 0.3606 | 0.1209 | 0.00273 |
| $X_1$, $X_2$, $X_4$ | 4 | 8 | 0.5479 | 0.3783 | 0.00193 |
| $X_1$, $X_3$, $X_4$ | 4 | 8 | 0.5695 | 0.4081 | 0.00184 |
| $X_2$, $X_3$, $X_4$ | 4 | 8 | 0.6092 | 0.4626 | 0.00167 |
| $X_1$, $X_2$, $X_3$, $X_4$ | 5 | 7 | 0.7543 | 0.6139 | 0.0012 |

[1] c-y d = cohort-year day; see Table 2.3.

[2] Juvenile rockfish $m^{-2}$.

[3] Variables in the model; $X_1$ = quadrate rugosity value; $X_2$ = density of rockfishes from previous cohorts per quadrate; $X_3$ = % macrophyte coverage per quadrate; $X_4$ = quadrate depth (MLLW).

[4] Parameters in the model.

[5] df = ANOVA degrees of freedom.

[6] $R^2$ = multiple correlation coefficient of the model.

[7] $R^2_a$ = multiple correlation coefficient of the model, adjusted for the number of variables in the model.

[8] MSE = ANOVA mean square error.

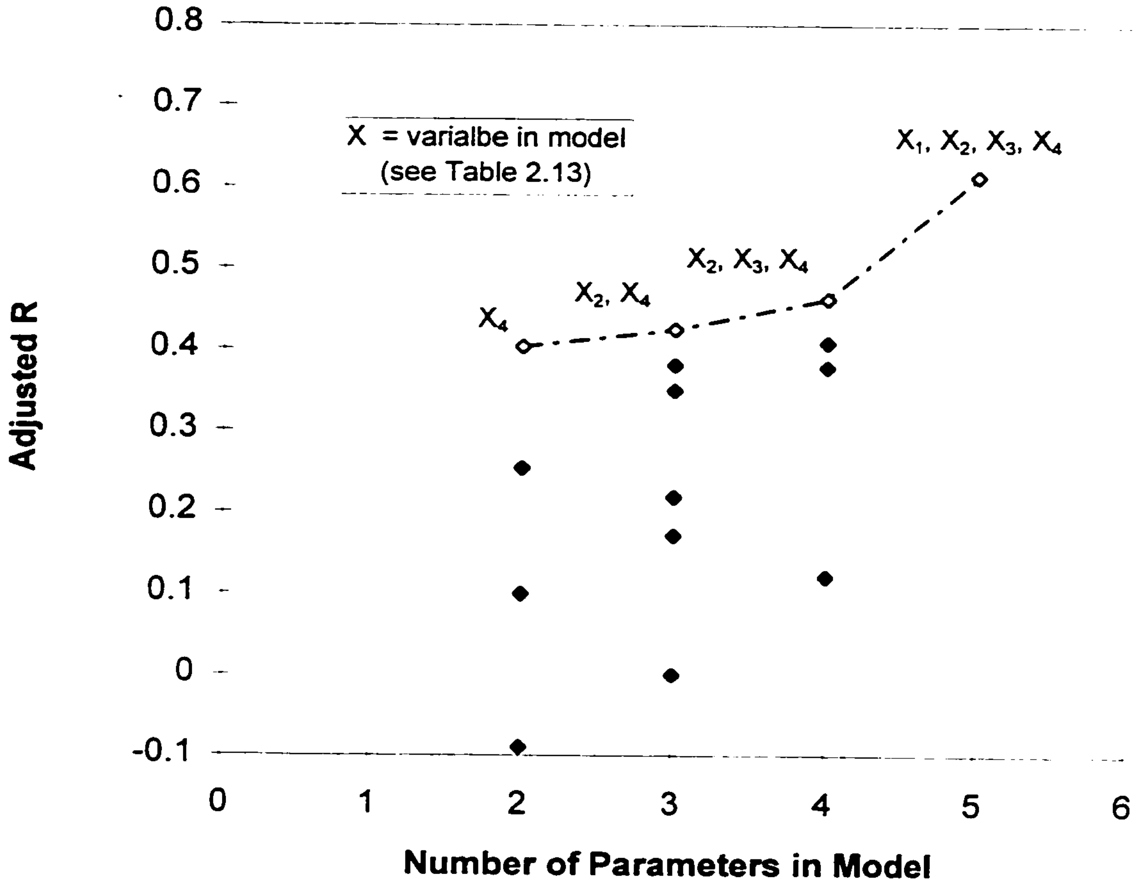


Figure 2.34. Adjusted $R^2$ values of the habitat use models for 1994 cohort juvenile quillback rockfish on Gedney Island Artificial Reef IRH during c-y d 68-116.

On GIAR ARH during c-y d 68-116, the quadrate rugosity values ($X_1$), and the depth of the quadrates ($X_4$), were positively correlated with juvenile quillback rockfish densities, but not significantly (CC; r = 0.259, p = 0.442, and r = 0.202, p = 0.552, respectively). The densities of *Sebastes* from previous years cohorts ($X_2$), and the areas of the quadrates covered by benthic macrophytes ($X_3$), were negatively correlated with juvenile rockfish densities, but not significantly (CC; r = -0.353, p = 0.288, and r = -0.448. p = 0.167, respectively). There was no significant linear relationship between the density of juvenile quillback rockfish and these habitat parameters on GIAR ARH during the early substrate associated recruitment period (ANOVA; F = 0.703, p = 0.618). There was no significant difference between the densities of juvenile quillback rockfish on GIAR ARH and IRH during the c-y d 68 and 116 period (t-test; $|t| = 0.171$, p = 0.866), but pooling the ARH and IRH habitat variables in a habitat use model resulted in no significant linear relationship between the density of juvenile quillback rockfish and these four habitat parameters (ANOVA; F = 1.224, p = 0.336).

Assessments of habitat use by juvenile quillback rockfish for the c-y d 143-297 period were not possible on GIAR ARH and IRH east and base habitats, due to patterns of temporally decreasing and then increasing densities (i.e., variable exposure to visual surveys) of juvenile rockfish during this period (see 1994 Recruitment to Artificial Reef Habitats). Juvenile quillback rockfish surveyed on GIAR ARH on c-y d 330, and on IRH on c-y d 343, appeared to be normally exposed to visual survey techniques. Surveys conducted on these dates did not include benthic macrophyte coverage of the quadrates as a habitat parameter, because the macrophytes had deteriorated substantially due to natural processes. The habitat parameters examined in the ARH and IRH east and base quadrates during these surveys were the substrate rugosity values ($X_1$), the densities of *Sebastes* from previous cohorts ($X_2$), and the depths of the quadrates ($X_3$; below MLLW; Appendix III and V.A, B).

On GIAR ARH during c-y d 330, the depths of the quadrates ($X_3$) were significantly positively correlated with juvenile quillback rockfish densities (CC; r = 0.622, p = 0.041). The quadrate rugosity values ($X_1$) were negatively correlated, and the densities of *Sebastes* from previous cohorts ($X_2$) were positively correlated, with juvenile rockfish densities, but not significantly (CC; r = -0.294, p = 0.683, and r = 0.133, p = 0.696, respectively). On GIAR IRH during c-y d 343, the quadrate rugosity values ($X_1$) and the densities of *Sebastes* from previous years cohorts ($X_2$) were positively correlated, and the depths of the quadrates ($X_3$) were negatively correlated, with the densities of juvenile quillback rockfish, but none of the correlations were significant (CC; r = 0.442, p = 0.150, r = 0.087, p = 0.789, and r = -0.050, p = 0.878, respectively). There were no significant linear relationships between the densities of juvenile quillback rockfish and these habitat parameters, on the ARH and IRH during these periods (ANOVA; F = 2.300, p = 0.164, and F = 0.669, p = 0.595, respectively).

**Growth and Survival of Juveniles on Artificial Reefs**

Measured samples of the 1991 cohort juvenile quillback rockfish on BCAR IRH (see 1991 Tagging on Boeing Creek Artificial Reef) were taken when juveniles were tagged and released on October 25 (c-y d 117), and from a collection on May 20 (c-y d 325; Table 2.3). On c-y d 117 the average size of the juveniles was 61.1 ± 7.3 mm TL (n = 56; Figure 2.7), and on c-y d 325 the average size of the juveniles was 84.9 ± 9.4 mm TL (n = 43; range 50 -101 mm TL). The 23.8

mm TL increase in average size during this 208 d period represents an average growth rate of 0.11 mm $d^{-1}$.

Temporal recoveries of 1991 cohort juvenile rockfishes identified with tags provided the best information on survival of the juveniles. The most reliable data for tag recoveries was from the nocturnal surveys and collections on BCAR IRH after 178d, when the juvenile rockfish were exposed to visual surveys (Figure 2.8). Using this data, the best estimates of the instantaneous rate of loss (i.e., natural mortality and possible emigration), and the survival rate, of the tagged fish over 258 d (i.e., tag release 0 d to 258 d; c-y d 117 to 374) are $Z = 0.0106$ and $S = 0.9895$, respectively ($r^2 = 0.84$; Figure 2.35).

Estimates of the lengths of the 1994 cohort juvenile quillback rockfish on BCAR ARH and IRH were made visually during the surveys for juvenile rockfish densities from c-y d 113 to 323 (see 1994 Recruitment to Artificial Reef Habitats; Figure 2.22). The 25.7 mm TL increase in average size over the 205 d period from c-y d 118 (i.e., the mid-point of c-y d 113-121 in numbers of fish in the sample) to c-y d 323, represents an average growth rate of 0.13 mm $d^{-1}$. The earlier surveys, from c-y d 118 to c-y d 191 (i.e., the temporal mid-point), found an 18.3 mm TL increase over this 73 d period (October 26 to January 7), representing a more rapid average growth rate of 0.25 mm $d^{-1}$. The later surveys, from c-y d 191 to 323, found a 7.4 mm TL increase over this 132 d period (January 7 to May 19), representing a decreased average growth rate of 0.06 mm $d^{-1}$.

Visual length estimates of the 1994 cohort juvenile quillback rockfish on GIAR ARH and IRH were made during the surveys for juvenile rockfish densities from

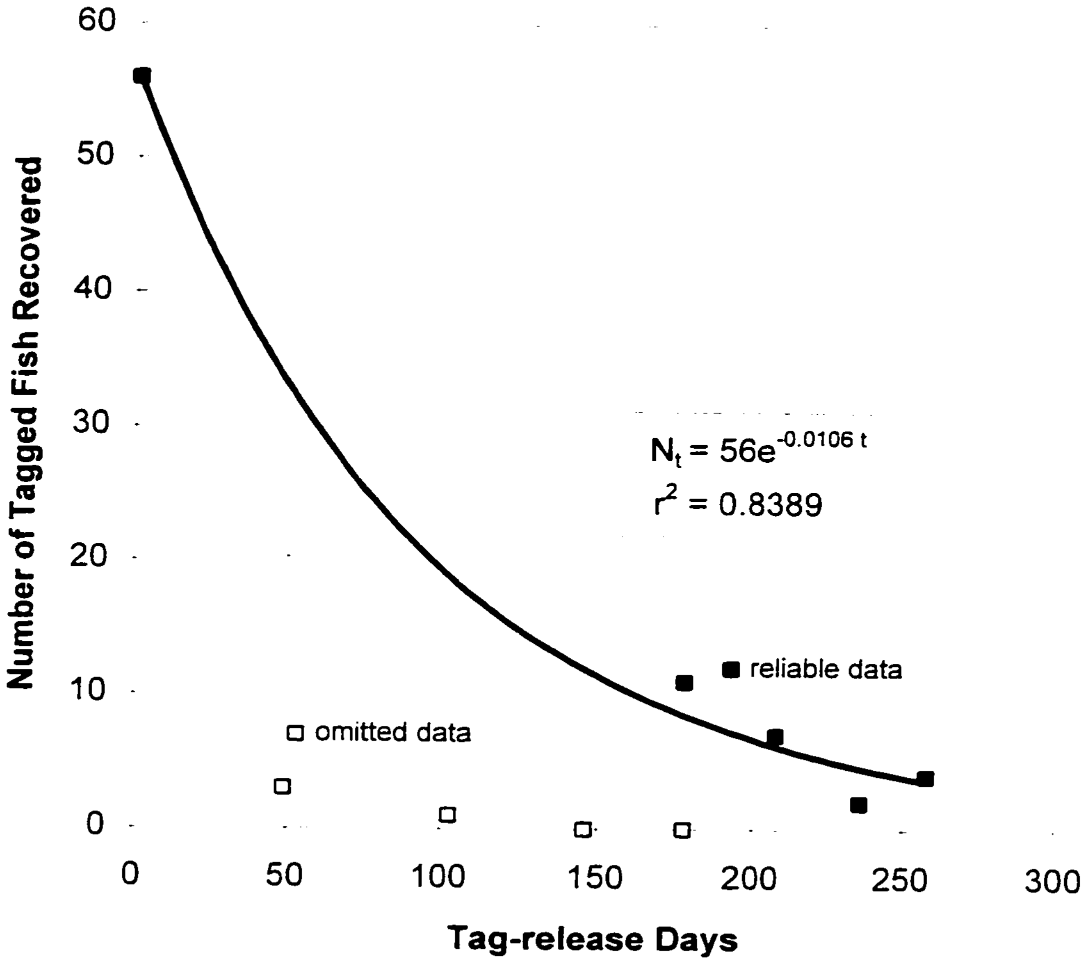


Figure 2.35. Survival of tagged 1991 cohort juvenile rockfish on Boeing Creek Artificial Reef IRH central habitat.

c-y d 116 to 343 (see 1994 Recruitment to Artificial Reef Habitats; Figure 2.23). The 23.8 mm TL increase in average length over the 219 d period from c-y d 116 to c-y d 335 (i.e., the mid-point of c-y d 330-343 in numbers of fish in the sample), represents an average growth rate of 0.11 mm $d^{-1}$.

## DISCUSSION

### Visual Survey Techniques

Few studies have been conducted on the important substrate associated juvenile recruitment period for rockfishes, in part because the complex biogenic habitats and benthic substrates used by these small juveniles created numerous physical barriers for most sampling techniques (Love et al. 1991). The underwater visual survey techniques used in this study reduced the affects of the physical barriers in a variety of complex natural and artificial reef habitats in northcentral Puget Sound. Underwater visual survey techniques used to study marine fishes are known to have observer biases (Sale and Douglas 1981, DeMartini and Roberts 1982, Sale and Sharp 1983, McCormick and Choat 1987), which most often result in under estimations of presence, abundance, or biomass (Brock 1982, Jennings and Polunin 1995). A number of modifications to visual survey techniques have been developed to offset biases in censuses of different species, or in different habitats (Jones and Thompson 1978, Bohnsack and Bannerot 1986, Smith 1989). Visual surveys remain the most practical and efficient technique for obtaining information on marine fishes in studies conducted underwater, at depths compatible with compressed air scuba equipment, and in habitats with high substrate complexity. The methods most commonly used to reduce within-study errors in underwater observations have been the development of specific survey protocols, and the use of the fewest number of observers possible to obtain the survey information.

The underwater visual surveys conducted in this study followed strict protocols to reduce potential within-survey sources of error caused by (1) failure to detect fish for censusing, (2) repeated censusing of the same fish, and (3) altering the normal distributions of the fish, either through attraction into a survey area, displacement out of a survey area, or herding into an adjacent survey area (see Quadrate Surveys, and Strip Transect Surveys). These protocols provided the most accurate assessments possible in the complex biogenic and benthic habitats under study; however, they did not overcome the seasonal behavior of the juvenile rockfishes in some artificial reef habitats, where the juveniles often used the crevices in the rock substrates as cryptic refuge habitats. Under these conditions, accurate surveys were not possible.

## Substrate Associated Recruitment Hypotheses

The overall objective of the Dissertation research presented in this study was to examine the substrate associated recruitment of juvenile copper rockfish and quillback rockfish in artificial reef and natural benthic habitats in northcentral Puget Sound, in order to compare and contrast recruitment parameters in these different habitats. The general hypotheses were (1) that juveniles of these species of rockfish utilized specific natural habitats with complex substrate characteristics during the juvenile substrate associated recruitment period, and that these habitats were important to juvenile survival and ontogenetic development, and (2) that manipulation of artificial reef substrates could simulate these recruitment habitats, which would enhance recruitment and survival of these juvenile rockfishes in artificial reef areas.

The findings of this study generally support the hypothesis that juvenile quillback rockfish and juvenile copper rockfish in northcentral Puget Sound utilized specific natural habitats with complex substrate characteristics during the substrate associated recruitment period, and that these habitats were important to juvenile survival and ontogenetic development. The levels of recruitment of the 1992, 1993, and 1994 cohorts of juvenile quillback rockfish in central Puget Sound natural habitats were sufficient to determine juvenile habitat use patterns, however, there were indications that initial substrate associated recruitment may have occurred on substrates with low complexity, followed by migrations to habitats with complex substrate characteristics. The low levels of recruitment of the 1992, 1993, and 1994 cohorts of juvenile copper rockfish in central Puget Sound natural habitats made it difficult to determine juvenile habitat use patterns for this species.

Substrate associated juvenile quillback rockfish from the 1992-1994 cohorts found in natural habitats, were exclusively associated with benthic macrophytes. Relatively large-sized juveniles in GIKM, MKM, and EKM were associated with the complex benthic macrophyte substrates, and were not found in the surface or mid-water macrophyte habitats formed by bull kelp fronds and stipes. Juveniles did not remain on the low complexity, partially exposed rock substrates in GIKM, MKM, or EKM after the natural seasonal losses of the benthic macrophytes. Juvenile quillback rockfish were also not found in eelgrass habitats near MKM, EKM, and BCAR; 1992 cohort juveniles found in eelgrass habitat near MKM in another study, were associated with, or in the vicinity of, patches of benthic macrophytes. Juvenile quillback rockfish were not found in limited surveys on open sand habitat, however, juveniles were found associated with drifting benthic macrophytes on sand habitat, at small sizes and early in the substrate associated recruitment period.

The limited numbers of 1992-1994 cohort juvenile copper rockfish found in natural habitats were associated with the complex benthic macrophyte substrates of GIKM, MKM, and EKM; the juveniles vacated the low complexity rock substrates in these habitats with the seasonal losses of the benthic macrophytes. Although 1992-1994 cohort juveniles were not found in eelgrass habitats near MKM, EKM, and BCAR, earlier studies of the 1990 and 1991 cohorts documented juvenile copper rockfish in eelgrass habitats in the central Puget Sound area. Juveniles were not found on sand habitat, although surveys of this habitat were limited.

These factors support substrate associated recruitment pathways for juvenile quillback rockfish and juvenile copper rockfish, progressing from pelagic juvenile habitats to specific natural nearshore benthic habitats with complex biogenic substrates. Recruitment of juvenile copper rockfish appears to be directly to the biogenic habitats. Recruitment of some, or all, juvenile quillback rockfish may be first to less complex habitats offshore, with subsequent migration to nearshore benthic macrophyte habitats. The importance and functions of these complex biogenic habitats to juvenile quillback rockfish and juvenile copper rockfish can only be completely determined through detailed trophic, growth, and behavioral studies. However, the behavior of several cohorts of juvenile rockfishes using these nearshore biogenic habitats as refuge and nursery habitats, and the seasonal movements of juveniles out of these nearshore habitats with the detached, drifting benthic macrophytes, supports the importance of these habitats to the survival and development of juvenile quillback rockfish and juvenile copper rockfish.

The findings of this study support the hypothesis that manipulations of artificial reef substrates simulate natural juvenile rockfish recruitment habitats with complex substrate characteristics, and enhance recruitment and survival of juvenile rockfishes in artificial reef areas. The levels of recruitment of 1991 cohort juvenile quillback rockfish to BCAR, and recruitment of 1994 cohort juvenile quillback rockfish to BCAR and GIAR, were sufficient to determine juvenile rockfish use of the ARH and IRH substrates. Habitat use surveys of the 1994 cohort recorded only one juvenile copper rockfish on BCAR and GIAR, combined.

The tagging study of 1991 cohort juvenile quillback rockfish on BCAR confirmed that juveniles recruited to the complex macrophyte and rock crevice IRH substrate, and that the juveniles used this substrate as refuge and nursery habitat for at least 285d. There were no indications of emigration of the juveniles from BCAR IRH, and the growth rates of the juveniles on this habitat were comparable to natural nearshore habitats. The survival rate of juvenile quillback rockfish on BCAR appeared to be good, but there are no other estimates of juvenile survival rates for this species, or other nearshore benthic rockfishes, for comparisons.

Surveys of substrate associated recruitment of 1994 cohort juvenile quillback rockfish in GIKM, MKM, EKM, BCAR, and GIAR, confirmed that juveniles recruited to similar complex substrates in these natural and artificial reef habitats, at similar times and sizes. Differences in the densities of juvenile quillback rockfish recruiting to, and persisting in, these habitats was related to spatial variations in recruitment of juvenile rockfishes in northcentral Puget Sound nearshore habitats, and to responses to natural temporal ecological parameters. Juvenile quillback rockfish in the benthic macrophytes on the shallower portions of BCAR north, central, and south habitats, did not vacate BCAR with the seasonal loss of the macrophyte habitat; the juveniles migrated to deeper portions of the ARH and IRH and used the crevices in the rock substrates as refuge and nursery habitats during the first cohort-year. GIAR ARH and IRH had little depth change throughout the habitats, and reduced seasonal changes in the benthic macrophytes, due to the deeper depths of the habitats; juvenile quillback rockfish remained on these deeper substrates, in the macrophyte and crevice habitats, during the first cohort-year. Increases in densities of juvenile quillback rockfish on BCAR IRH and GIAR ARH and IRH late in the cohort-year indicated immigration to these habitats by juveniles, either (1) progressively during the cohor-year but detected only at the end of the cohort-year when the juveniles emerged form the crevice habitats and were more visible, or (2) at the end of the cohort-year. The source of these juvenile quillback rockfish was most likely juveniles that had recruited to other habitats with less refuge potential and fewer food resources.

These factors support BCAR and GIAR ARH and IRH substrates functioning as effective recruitment, refuge, and nursery habitats for juvenile quillback rockfish, both for juveniles recruiting to these areas early in the substrate associated recruitment period, and for juveniles migrating to these areas after recruiting to other habitats. Juvenile rockfishes did not recruit to, or did not survive on, the original artificial reef substrates at BCAR and GIAR; only two 1994 cohort juvenile quillback rockfish were found on the original artificial reef substrate at

BCAR, and none were found at GIAR. There were no significant differences in the densities of 1994 cohort juvenile quillback rockfish on the ARH and IRH at BCAR or at GIAR, over the cohort-year, indicating that both manipulations of the artificial reef substrates functioned equally effectively in enhancing the recruitment and survival of juvenile rockfishes in the artificial reef areas. This does not support studies of 1991 and 1992 cohorts of juvenile rockfishes on BCAR and GIAR, which found significantly higher densities of juveniles on the IRH at both locations (West et al. 1995). This difference may be due to, in part, to the low levels of recruitment of the 1994 cohort, and various density dependent ecological factors not detailed in this study.

## Spatial and Temporal Parameters and Recruitment Pathways

A specific objective of this study was too assess the substrate associated recruitment of juvenile copper rockfish and quillback rockfish from the 1991-1994 cohorts, in a variety of natural and artificial reef habitats in northcentral Puget Sound, with regard to spatial and temporal parameters of recruitment, and recruitment habitat pathways, of the juvenile rockfishes. The spatial and temporal parameters of settlement of pelagic juvenile quillback rockfish and copper rockfish to substrates in northcentral Puget Sound, as the first substrate associated recruitment of the cohorts, undoubtedly varied between species and, to a lesser extent, between years. Recruitment habitat pathways for each of these species should have been far less variable, however, as this parameter is part of the genetically-related processes for selection of appropriate habitats that lead to successful recruitment and survival.

The surveys of nearshore habitats at EKM, MKM, and BCAR for settlement of the 1994 cohorts of these species were the first repeated examinations of bull kelp, benthic macrophyte, eelgrass, rocky-reef, and sand habitats, in a known settlement area in Puget Sound, to determine the timing of substrate associated recruitment for these rockfishes (see Table 2.6) and the early recruitment pathways. These surveys provided good information for juvenile quillback rockfish, although recruitment levels were substantially below previous years (see Juvenile Densities and Habitat Selection and Use). These surveys did not yield any information on juvenile copper rockfish due to the almost complete absence of the 1994 cohort in northcentral Puget Sound.

The first 1994 cohort juvenile quillback rockfish were found on c-y d 54-55 (August 23-24) associated with drifting benthic macrophytes on the sand habitat adjacent to BCAR. These were the earliest and smallest (n = 19, range 31-56 mm TL, average 44.8 ± 6.6 mm TL) post-pelagic quillback rockfish ever recorded in this region. The earlier (i.e., spring season) settlement date reported by Mathews (1989, 1990) for 1987 and 1988 cohort juvenile rockfishes (assumed to be primarily quillback rockfish; Mathews 1989) on BCAR resulted from incorrect species identification (see Chapter 5). In addition, juvenile quillback rockfish had never been verified in this region on nearshore sand habitat in association with drifting benthic macrophytes; they were more commonly found in association with attached understory benthic macrophytes in bull kelp beds, later in the cohort-year. Surveys of a natural reef in central Puget Sound noted that 1987 cohort juvenile rockfishes (copper, quillback, and brown combined) were first found in July on sand and *Agarum* sp. habitat adjacent to the reef, and then found in August associated with the reef habitat (Mathews 1990).

Juvenile quillback rockfish from the 1994 cohort were first found in attached benthic macrophyte habitats at EKM (average 60.3 mm TL) and MKM (average

57.9 mm TL) on c-y d 59 and 63, respectively. A subsequent survey of GIAR ARH and IRH on c-y d 68 found juvenile quillback rockfish (visual estimate average 70 mm TL) on both habitats. Surveys of BCAR IRH on c-y d 72 (September 10) found juvenile quillback rockfish (average 56.7 mm TL) in unattached macrophytes (*L. saccharina* and *D. munda*) on the rocks of the nearshore end of the central habitat. Surveys of BCAR IRH on c-y d 113 (October 21) found juvenile quillback rockfish (average 61.3 mm TL) in attached macrophytes (primarily *L. saccharina*) on the nearshore end of the south habitat. These juveniles on BCAR were comparable in size to the juvenile quillback rockfish found at EKM and MKM, indicating that substrate associated recruitment to nearshore rocky reef and macrophyte habitats occurs by late August to early September, of the first cohort-year. No 1994 cohort juvenile quillback rockfish were found in surface habitat formed by bull kelp fronds, or mid-water bull kelp stipe habitat, or in benthic eelgrass habitat and sand habitat.

An early to middle of August (approximately c-y d 32-46) timing for the settlement of substrate associated recruitment of juvenile quillback rockfish in northcentral Puget Sound, and subsequent movement of juveniles into nearshore bull kelp and macrophyte habitats, is in agreement with surveys of previous cohorts in this area. Mathews (1988) reports the first 1987 cohort juvenile rockfishes (an unknown mixture of quillback, copper, and brown rockfish) were found during August surveys on nearshore natural reef and artificial reef habitats in central Puget Sound. Juvenile quillback rockfish from the 1992 cohort (n = 13, range 62-75 mm TL, average 66.8 ± 3.6 mm TL) were first found on c-y d 80 (September 18) in a bull kelp and benthic macrophyte habitat 4.3 km south of BCAR (Washington Department of Fish and Wildlife, unpublished). Other surveys in central Puget Sound for recruitment of juvenile rockfishes from the 1991, 1992, and 1993 cohorts, found juvenile quillback rockfish in nearshore macrophyte and artificial reef habitats at later dates, and at larger average sizes, but these surveys were the first conducted in the particular habitats for the cohort-year and did not accurately reflect sequential temporal recruitment parameters (Washington Department of Fish and Wildlife, unpublished).

Although there were few 1994 cohort copper rockfish in northcentral Puget Sound, it appears from surveys of recruitment of previous cohorts in this area that juvenile copper rockfish enter the first substrate associated phase of recruitment in nearshore habitats somewhat earlier, and at a smaller size, than juvenile quillback rockfish. It also appears that early substrate associated recruitment of juvenile copper rockfish occurs in eelgrass habitat, as well as bull kelp and benthic macrophyte habitat. The accuracy of many of these surveys is confounded, however, because species were not identified. This resulted in juvenile copper rockfish and quillback rockfish being combined, sometimes with juvenile brown rockfish.

A middle of July, to early August (approximately c-y d 15-46) timing for the first substrate associated recruitment of juvenile copper rockfish in northcentral Puget Sound, and the movement of juveniles that first recruited to eelgrass habitat to nearshore bull kelp and macrophyte habitats, is in agreement with surveys of previous cohorts in this area (see Chapter 3). Juvenile rockfishes from the 1987 cohort (possibly copper rockfish) were found about c-y d 20 (about July 20) in eelgrass habitat in central Puget Sound, but vacated the eelgrass habitat by August surveys (Mathews 1988, 1990). Juvenile rockfish from the 1990 cohort (most likely copper rockfish; n = 6, range 23-45 mm TL, average 34.2 ± 7.5 mm

TL) were found on c-y d 44 (August 13) in eelgrass habitat 1.9 km north of BCAR; 1991 cohort juveniles (most likely copper rockfish; n = 3, range 31-37 mm TL, average 34.7 ± 2.6 mm TL) were found on c-y d 59 (August 28) in macrophyte habitat 6.6 km south of BCAR (Shilshole Bay; Washington Department of Fish and Wildlife, unpublished). Juvenile rockfish from the 1991 cohort (predominately copper rockfish; n = 28, range 21-37 mm TL, average 27± 0.9 mm TL) were also found on about c-y d 15 (i.e., mid-July) in mixed eelgrass and benthic macrophyte habitats 4.3 km south of BCAR (Carkeek Park; Doty et al. 1995). Recruitment of 1985 cohort juvenile copper rockfish (range of average fork lengths, 36.5 to 42.2 mm) occurred about c-y d 32-38 (i.e., August 1-7) in macrophyte and eelgrass habitats 200 km north-northwest of central Puget Sound (Strait of Georgia; Haldorson and Richards 1987).

Surveys in central Puget Sound for recruitment of juvenile rockfishes from the 1991 and 1992 cohorts, found juveniles suspected to be copper rockfish in nearshore macrophyte, eelgrass, and artificial reef habitats at later dates, and at larger average sizes (Washington Department of Fish and Wildlife, unpublished). Many of the 1992 cohort juvenile copper rockfish found in eelgrass habitat (approximately c-y d 100) were closely associated with small areas of attached benthic macrophytes (primarily *L. saccharina*) that were mixed in the eelgrass habitat (author, personal observation); therefore, substrate association of the juveniles with eelgrass habitat later in the cohort-year is not confirmed. Many of these earlier surveys were exploratory, and were the first conducted in the particular habitats for the cohort-year, and therefore did not accurately reflect sequential temporal recruitment parameters.

The repeated surveys for 1994 cohort juvenile rockfishes on BCAR and GIAR, and the sequential surveys for tagged 1992 cohort juvenile rockfishes in GIKM, and tagged 1993 cohort juveniles in EKM, confirm that juvenile quillback rockfish have a single, fall season, substrate associated recruitment period in northcentral Puget Sound. A single recruitment period was also recorded for 1991 cohort juvenile rockfishes (quillback, copper, and brown rockfish combined) to BCAR (West et al. 1995), and to a mixed eelgrass and benthic macrophyte habitat 4.3 km south of BCAR (Doty et al. 1995). The spring and fall season recruitment periods reported by Mathews (1988, 1990) for 1987 and 1988 cohort juvenile quillback rockfish on BCAR resulted from incorrect species identification (see Chapter 5).

The recruitment of 1994 cohort juvenile quillback rockfish on BCAR and GIAR was somewhat protracted over mid-August through October, but it was a single recruitment period as there were unimodal length-frequency distributions for the juvenile rockfishes on BCAR and GIAR for the cohort-year (see Figures 2.22 and 2.23). The small-sized 1994 cohort recruits (40-70 mm TL) were not found in surveys on BCAR after c-y d 115, or in surveys on GIAR after c-y d 116. The releases of tagged groups, and subsequent tag recovery surveys, of 1992 cohort juvenile quillback rockfish in GIKM over 62 d (c-y d 104-168), and of 1993 cohort juvenile quillback rockfish in EKM over 124 d (c-y d 93-217), did not recorded any additional recruitment of juveniles in these habitats. Doty et al. (1995) note that early settlement-sized (i.e., 19-21 mm TL) 1991 cohort juvenile rockfishes (quillback, copper, and brown rockfish combined) were found from mid-July through October (c-y d 15-123) in eelgrass and benthic macrophyte habitats in central Puget Sound (including GIKM, MKM, and EKM), indicating a single, protracted recruitment period.

It seems probable that juvenile copper rockfish also have a single, fall season, substrate associated recruitment period in northcentral Puget Sound. This is difficult to confirm, because the repeated surveys of BCAR and GIAR provided little information on 1994 cohort juvenile copper rockfish due to extremely low recruitment in this area. The 1992 tagging study in GIKM, and the 1993 tagging study in EKM, also found too few juvenile copper rockfish to estimate temporal recruitment parameters. However, juvenile copper rockfish were more abundant in surveys of 1991 and 1992 cohort juvenile rockfishes (quillback, copper, and brown rockfish combined) in central Puget Sound, which found only single, fall season, recruitment periods (Doty et al. 1995, West et al. 1995, Washington Department of Fisheries, unpublished). Single recruitment periods were also noted during studies of 1963, 1964, and 1965 cohorts of copper rockfish on a natural reef habitat, and an artificial reef, in central Puget Sound (October recruitment; Patten 1973), and during surveys of 1987 cohort rockfishes (quillback, copper, and brown rockfish combined) on natural rocky reefs (August-October recruitment; Mathews 1988, 1990). A single, early August recruitment period was noted for 1985 cohort copper rockfish in natural habitats 200 km north-northwest of central Puget Sound (Haldorson and Richards 1987).

The recovery of tagged 1991 cohort juvenile quillback rockfish over 258 d, only on BCAR IRH central habitat where they were released, indicates restricted spatial recruitment parameters for juveniles after substrate associated recruitment to stationary nursery habitats with abundant crevices for refuge. Although the ARH and IRH of BCAR and GIAR were constructed at ecologically relevant scales, these artificial reef refuge habitats were somewhat atypical of nearshore habitats in central Puget Sound, in that (1) they created areas with high densities of crevice-refuge habitat, surrounded by expanses of sand habitat with extremely low potential for ecologically similar refuge habitat, and (2) they did not have large amounts of potentially mobile benthic macrophyte habitat, when compared to natural nearshore rocky areas. This could have resulted in spatial recruitment parameters for the juvenile quillback rockfish to the ARH and IRH areas that were atypical; that is, there may have been little need or incentive for the juvenile quillback rockfish to redistribute to other areas, and little opportunity to do so and still maintain association with refuge habitat.

The surveys for tagged 1992 cohort juvenile quillback rockfish in GIKM, and tagged 1993 cohort juveniles in EKM, found that juveniles were strongly associated with the biogenic refuge habitats formed by the benthic macrophytes, but that juveniles demonstrated variable spatial recruitment parameters within these habitats, in that they were decreasingly stationary, or site specific. There were substantial decreases in densities of tagged and non-tagged 1992 cohort juvenile quillback rockfish in GIKM during c-y d 133-168 (November 10 to December 15). There were no recoveries of the second group (n = 95) of tagged 1993 cohort juvenile quillback rockfish in EKM on c-y d 137 (November 14; 9 d after release), and no tagged or non-tagged juveniles were found during c-y d 191-204 (January 7-20). The November through January period is when the biogenic habitat in nearshore areas of central Puget Sound normally becomes detached from the substrate, due to natural seasonal processes, and is transported out of the nearshore areas by tidal currents. Temporal decreases in juvenile quillback rockfish densities concurrent with displacement of biogenic refuge habitat, combined with initial substrate associated recruitment of juvenile quillback rockfish to macrophyte substrates, strongly indicates that the juveniles were transported out of GIKM and EKM with the detached macrophytes, as a normal spatial parameter of recruitment in nearshore habitats. Surveys of 1992 cohort juvenile rockfishes (quillback, copper, and brown rockfish combined) in natural bull kelp and macrophyte habitats in central Puget Sound that had limited substrate crevices, found that juvenile rockfish densities decreased in November and December, with juveniles rarely found in these nearshore habitats during January to July (Doty et al. 1995).

### Juvenile *Sebastes* Densities and Habitat Selection and Use

A specific objective of this study was too assess the substrate associated recruitment of juvenile copper rockfish and quillback rockfish from the 1991-1994 cohorts, in a variety of natural and artificial reef habitats in northcentral Puget Sound, with regard to juvenile rockfish densities and habitat selection and use. Only one 1994 cohort juvenile copper rockfish was recorded on BCAR and GIAR, combined.

The densities of 1994 cohort juvenile quillback rockfish during early substrate associated recruitment on BCAR ARH (0.004 fish $m^{-2}$; c-y d 72-115) and IRH (0.048 fish $m^{-2}$; c-y d 72-113), appeared to be the lowest levels of juvenile rockfish recruitment recorded for these artificial reef habitats. Densities of 1991 cohort juvenile rockfishes (i.e., quillback, copper, and brown rockfish combined) during October (approximately c-y d 93-123) on BCAR ARH and IRH, were 0.013 fish $m^{-2}$ and 0.120 fish $m^{-2}$, respectively (West et al. 1994); the densities of 1992 cohort juvenile rockfishes during September (approximately c-y d 63-92) on the ARH and IRH were 0.060 fish $m^{-2}$ and 0.080 fish $m^{-2}$, respectively (Washington Department of Fish and Wildlife, unpublished).

Densities of 1994 cohort juvenile quillback rockfish during this period on GIAR ARH (0.053 fish $m^{-2}$; c-y d 68-116) and IRH (0.049 fish $m^{-2}$; c-y d 68-116), appeared to be the second lowest levels of juvenile rockfish recruitment recorded for these habitats. Densities of 1991 cohort juvenile rockfishes during November (approximately c-y d 124-153) on GIAR ARH and IRH were 0.470 fish $m^{-2}$ and 0.540 fish $m^{-2}$, respectively (West et al. 1994); the densities of 1992 cohort juvenile rockfishes during September (approximately c-y d 63-92) on the ARH and IRH were 0.030 fish $m^{-2}$ and 0.020 fish $m^{-2}$, respectively (Washington Department of Fish and Wildlife, unpublished).

The densities of substrate associated juvenile rockfishes on the ARH and IRH of BCAR and GIAR, during the cohort-year, varied considerably between the ARH and IRH substrates, and between cohort-years. The densities of 1991 and 1992 cohort juveniles were higher on the IRH than the ARH at BCAR (West et al. 1995). For GIAR, the density of 1991 cohort juveniles was higher on the IRH than the ARH, and, under relatively low levels of recruitment, the density of 1992 cohort juveniles was higher on the ARH (West et al. 1995; Washington Department of Fish and Wildlife, unpublished). In contrast, and under relatively lower levels of recruitment, and virtually no juvenile copper rockfish, there were no differences in the densities of 1994 cohort juvenile quillback rockfish on the ARH and IRH at both BCAR and GIAR.

The apparent differences in densities of juvenile rockfishes between cohort-years, and between artificial reef recruitment areas, could be artifacts of temporal variability in detection of juveniles in visual surveys (see 1994 Recruitment to Artificial Reefs). West et al. (1995) interpreted the differences between densities of 1991 and 1992 cohort substrate associated juvenile rockfishes on the ARH and IRH substrates, as indications of higher levels of recruitment, or higher levels of survival, or both, on the IRH substrates. It was speculated that the lower densities of juveniles on the ARH substrates were possibly responses to the proximity of the ARH substrates to the original artificial reefs at BCAR and GIAR, with their resident populations of rockfishes from previous cohorts; densities of these older rockfishes were significantly greater on the ARH than the IRH (West et al. 1995). However, during the 1994 cohort-year, densities of rockfishes from previous cohorts were significantly greater on the IRH than the ARH at BCAR, but greater on the ARH than the IRH at GIAR. In addition to the potential for sampling errors due to temporally variable detection of juveniles, the lack of consistent differences between juvenile rockfish densities on the ARH and IRH substrates may also indicate that the efficacies of these habitats are, at a minimum, affected by variability in levels of recruitment, variability in biogenic habitat parameters, or the increased ecological maturity of the substrates. The affects of these parameters on juvenile rockfish recruitment have not been determined, and consistent differences between ARH and IRH designs are needed to determine the optimal artificial reef configuration for enhancing juvenile *Sebastes* recruitment habitat in Puget Sound.

The tagging study of 1991 cohort juvenile quillback rockfish on BCAR found that habitat use varied between diurnal and nocturnal periods in surveys during c-y d 166-295; the higher densities of both tagged and non-tagged juveniles during the nocturnal surveys were the result of the juveniles being out of the refuge crevices in the reef substrate, and visible during the surveys. Although it was not determined through trophic studies, it seem likely that the juvenile quillback rockfish were out of the crevice habitats to forage for benthic crustacean prey during darkness, perhaps when their risks for predation were reduced. Juvenile quillback rockfish were frequently observed, during diurnal surveys of BCAR, GIAR, GIKM, EKM, and MKM, feeding on small crustaceans associated with the benthic macrophytes, and often with the antennae of juvenile coonstripe shrimp (*Pandalus danae*) protruding from the buccal cavity (Washington Department of Fish and Wildlife, unpublished).

A nocturnal feeding pattern for juvenile quillback rockfish would contrast the primarily mid-day feeding pattern of older (i.e., sub-adult and adult) quillback rockfishes, but would interact with the primarily crepuscular feeding pattern of older copper rockfish (Murie 1991). During the 1994 cohort-year, these older quillback rockfish were present in much higher densities than older copper rockfish on the ARH, IRH, and original artificial reef at BCAR, and on the ARH and IRH at GIAR; older quillback rockfish and copper rockfish densities were about the same on the original artificial reef at GIAR (see Table 2.11). If there was temporal partitioning in the feeding patterns between juvenile and older rockfishes, possibly based on risks from predation by the older rockfishes, juvenile rockfishes would seem to have benefited from feeding at night to avoid the more abundant quillback rockfish. This would be especially relevant during the winter months when adult quillback rockfish and adult copper rockfish are feeding at increased rates to offset reproductive demands (Murie 1991). However, high levels of cannibalism and intra-generic predation in *Sebastes* are in question (see Cannibalism and Other Predation).

During the diurnal surveys in the 1991 and 1994 cohort-years, juvenile and sub-adult (i.e., smaller adult) rockfishes were found using crevices in the rock substrate as refuge habitat on the ARH and IRH of BCAR and GIAR, during c-y d 185 to 305 (i.e., January through April). It was common to observe many partially exposed rockfishes seemingly wedged in the crevices in the substrate, often two or three layers of rock below the surface of the reef. This temporal pattern of habitat use was also reported for juvenile rockfishes during diurnal surveys of the 1991 and 1992 cohorts on low relief artificial reef substrates (i.e., the ARH and IRH formed from small rocks) in central Puget Sound (West et al. 1995), but was not reported in diurnal surveys of 1987 and 1988 cohort juvenile rockfishes on the high relief substrate (i.e., the original reef formed from large rocks) on BCAR (Mathews 1988, 1990). The surveys on the original artificial reef at BCAR during the 1994 cohort-year, noted some rockfishes deep within the large cave-like crevices during c-y d 185 to 305, but the crevices penetrated deep into the reef substrate and were inaccessible to divers for assessments of the numbers of fish possibly using this refuge habitat.

The pattern of apparently temporally decreasing (starting in January), and then increasing (starting in April), densities of juvenile rockfishes on BCAR (1991 and 1994 cohorts) and GIAR (1994 cohort) was caused by the reduced detectability of the juveniles in visual surveys, when they were hiding in crevice habitats. The frequency of the observations of this behavior in juvenile rockfishes on BCAR and GIAR ARH and IRH, over several cohort-years, indicates that this was apparently a normal response to one or more environmental parameters, such as low water temperature, or reduced levels of irradiance, during the winter months. Average monthly temperatures on nearshore habitats in central Puget Sound have been monitored by several researchers (e.g., BCAR; Mathews 1988), and the lowest temperatures occurred from January through April (i.e., range 7.1 to 8.2 °C; see Mathews 1988). It is not known if this co-occurance of seasonal low water temperatures, and diurnal use of crevice habitats by juvenile rockfishes on ARH and IRH substrates, represents a partial, or complete, cause and effect relationship. The behavior of responding to winter environmental parameters by hiding, or torpor, has been noted in other demersal temperate marine fishes (Olla et al. 1974, 1975), and this behavior has resulted in apparent reductions in densities of these fishes during this period.

The temporal increases in average densities of 1994 cohort juvenile quillback rockfish in the surveys late in the cohort-year on BCAR IRH and GIAR ARH, to levels considerably larger that the initial levels of recruitment (see 1994 Recruitment to Artificial Reefs; see Figures 2.25 and 2.30), indicate possible recruitment or immigration of juveniles to these habitats over time. Recruitment over time does not support the temporal recruitment parameter of single recruitment periods found for the 1991-1994 cohorts of juvenile rockfishes. Immigration of juveniles does not support the habitat use pattern of restricted spatial movements after substrate associated recruitment to artificial reef substrate habitats found over 258 d for the 1991 cohort tagging study on BCAR IRH. The single recruitment periods are based on temporal length frequency distributions of four cohorts from several areas. The restricted spatial distribution of juvenile rockfishes on the artificial reef recruitment substrates is supported only by evidence from a single tagged cohort on BCAR, but the identification of the juveniles with tags validated the restricted movement pattern. Inter-habitat movements of juveniles could have occurred, with juveniles moving onto the artificial reef recruitment substrates after recruiting to other habitats with less refuge potential; however, movements between ARH and IRH areas were highly unlikely due to the large distances separating these habitats (i.e., 200 m for BCAR and 300 m for GIAR; see Figures 2.4 and 2.5). The elevated densities of juveniles were found on BCAR IRH base habitat, and on GIAR ARH base habitat and IRH east habitat, indicated no apparent pattern relative to juxtapositions with the original artificial reef substrates at either location. These anomalous recruitment densities in the last surveys of the cohort year were most likely related to low levels of recruitment of 1994 cohort juvenile quillback rockfish to BCAR and GIAR, immigration to unoccupied refuge habitat on the artificial reefs, and the limited visual detectability of juveniles until they emerged from the crevice habitats just prior to the last surveys.

The natural bull kelp and macrophyte habitats at GIKM, MKM, and EKM were formed by attachment of the plants on mainly rounded rocks protruding from the substrate. This configuration of the rock substrate provided few crevice habitats for juvenile rockfishes. In these habitats, juvenile rockfishes used the dense understory macrophytes as refuge habitat. In the early substrate association phase, juvenile quillback rockfish from the 1992 cohort in GIKM, the 1993 cohort in EKM, and the 1994 cohort in EKM and MKM, were found mainly in loose schools, closely associated with benthic macrophytes; these schools later dispersed, and the juveniles moved into the habitat formed by the blades of the macrophytes. The ability of the juvenile rockfishes to move through this relatively loose refuge habitat formed by the abundant benthic macrophytes, as opposed to seeking refuge in stationary crevices in the rocks, appeared to allow the juveniles optimal trophic and protective use of the biogenic habitat. The detachment of the macrophytes from the substrate, during normal seasonal deterioration processes, formed the macrophytes into benthic drift habitat, which was transported out of GIKM, EKM, and MKM by tidal currents. Based on the strong association of juvenile quillback rockfish with benthic macrophyte substrates during this period in the cohort-year, and rapid decreases in densities of 1992 cohort juveniles in GIKM, and 1993 cohort juveniles in EKM, it was assumed that the juveniles were transported out of these nearshore habitats with the detached macrophytes. This is supported by qualitative observations during the surveys that there were no obvious changes in the fish communities in GIKM and EKM during the periods when densities of juvenile rockfish decreased rapidly; that is, there were no influxes of potential predators.

During the 1992 cohort tagging study in GIKM, the rapid decrease in densities of juvenile quillback rockfish from c-y d 133 to 168 (0.042 fish $m^{-2}$ to 0.012 fish $m^{-2}$, respectively) indicated that the juvenile rockfish were rapidly leaving the nearshore habitat during the natural deterioration and transport of the benthic macrophyte habitat. During the 1993 cohort tagging study in EKM, there were no tag recoveries from the second tagged group released on c-y d 128, during surveys from c-y d 137 to 217. This indicated that, by the time of the second release of tagged juvenile quillback rockfish, the juveniles were rapidly leaving EKM, most likely with the detached macrophytes. The densities of non-tagged juvenile quillback rockfish in EKM also declined rapidly during this period. The mobility of the juvenile rockfish in loose macrophyte habitat may have resulted in some juveniles being less detectable in visual surveys, thereby artificially lowering density estimates; however, this was a minimal source of error as the macrophytes were physically displaced during the surveys (see Strip Transect Surveys), increasing the visibility of any juveniles.

The seasonal habitat use pattern of juvenile quillback rockfish moving out of bull kelp and macrophyte habitats with drift macrophytes, was apparently altered by the patch reef habitats constructed in EKM in 1993. Diurnal surveys of the patch reefs on c-y d 191 (i.e., January 7) did not find any juvenile rockfishes; however, nocturnal surveys of the patch reefs on c-y d 204, found five 1993 cohort juvenile quillback rockfish (range 60-70 mm TL; average 68 ± 4.0 mm TL) using the crevice habitats formed when the natural rocks were dislodged from the substrate and piled in a patch reef configuration. This use of crevices in the substrate in nearshore habitats as refuge habitat, is the same habitat use pattern found for several cohorts of juvenile quillback rockfish on BCAR and GIAR ARH and IRH. In EKM, the juvenile quillback rockfish apparently remained in the nearshore crevice refuge habitat in preference to migrating with the detached macrophyte (biogenic) refuge habitat. This indicates that the association of juvenile rockfishes with macrophyte substrates in nearshore habitats, and the subsequent migration of the juveniles with the macrophytes, may be strongly associated with the refuge potential of the habitat, and less related to any trophic value of organisms associated with the habitat.

It appears that juvenile quillback rockfish also use detached, drifting macrophyte habitat early in the substrate associated recruitment period, as a recruitment pathway when migrating across sand habitat to nearshore habitats with greater refuge and trophic value. This habitat use pattern is supported by the small-sized 1994 cohort juvenile quillback rockfish found associated with detached macrophytes drifting over sand habitat, adjacent to the BCAR ARH and IRH, prior to recruitment of any juveniles to the ARH or IRH rock and macrophyte substrates. West et al. (1995) also reported qualitative observations of juvenile rockfishes closely associated with benthic drifting macrophytes and seagrass near BCAR, early in the substrate associated recruitment period of the 1992 cohort, and, further, that this drifting vegetation often became entrained on the ARH and IRH rock substrates. A comparable recruitment pathway for juvenile quillback rockfish was not detected in the surveys of 1994 cohort recruitment to GIAR ARH and IRH; however, similar habitat use could have occurred as extensive off-reef surveys were not conducted at GIAR to detect drifting macrophyte habitat. The detection of this recruitment pathway at BCAR was the result of the opportune fouling of drifting macrophytes on plastic pipe stakes in the sand substrate, which prevented the drift macrophytes from reaching the ARH and IRH substrates.

The habitat use models correlating the affects of various habitat variables on the densities of juvenile quillback rockfish during early substrate associated recruitment on BCAR IRH (i.e., c-y d 72-113) and GIAR IRH (i.e., c-y d 68-116), demonstrated the importance of substrate and benthic biogenic habitat complexity in the recruitment process for this rockfish. BCAR ARH received insufficient recruitment of juvenile quillback rockfish during early substrate associated recruitment (c-y d 72-115; only 1 recruit on c-y d 115) for meaningful assessment of habitat use (see 1994 Recruitment to Artificial Reef Habitats). The same suite of habitat variables were monitored on the ARH as on the IRH at BCAR (see Appendix IV.A, B), and there were no significant differences in these variables between the refuge substrate locations (see 1994 Macrophyte and Substrate Profiles of Artificial Reefs). This indicates that the lack of juvenile quillback rockfish recruits on BCAR ARH was not the result of habitat profile differences. The low levels of recruitment on BCAR ARH may have been due, in part, to the presence of moderate densities of *Sebastes* from previous cohorts on the shallow north, central and south habitats during the early substrate associated recruitment period; West et al. (1994, 1995) indicate that juvenile rockfishes may avoid older rockfishes during recruitment. GIAR ARH received relatively good levels of recruitment of juvenile quillback rockfish during early substrate associated recruitment, but there was no significant relationship between the densities of juveniles and habitat use parameters monitored in this study (see 1994 Cohort Habitat Use Models).

On BCAR IRH, the amount of rock habitat area was significantly correlated with the density of juvenile quillback rockfish independent from, and in, the habitat use model, demonstrating that the refuge habitat formed by the substrate crevices is a key habitat use parameter. The number of bull kelp stipes (i.e., plants) was not significantly correlated with juvenile density independent from the model, however this biogenic habitat variable contributed significantly in the model. In contrast, benthic macrophyte coverage of the substrate was significantly correlated with juvenile density independent from, and in, the model. This seems to indicate that the vertical structure of the bull kelp through the water column to the surface, was not as important to recruitment of juvenile quillback rockfish, as the contribution of the bases of the plants to the benthic macrophyte habitat structure; this contribution apparently resulted both from the physical structure created by the stipes, and the entrainment by the stipes of benthic macrophytes moving in tidal currents.

On GIAR IRH, the depth of the recruitment substrate was the only habitat variable that was significantly correlated with the densities of juvenile quillback rockfish during early substrate associated recruitment, independent from, and in, the habitat use model; this positive correlation with depth indicates that there may have been an offshore component to the early substrate associated recruitment pathway for the juveniles. The other variables, rugosity value of the substrate, the densities of *Sebastes* from previous cohorts, and the coverage of the substrate by benthic macrophytes, all contributed significantly in the habitat use model. The rugosity values of the substrate, which are highly correlated with the amounts of refuge habitat formed by the substrate crevices (see Correlation Study and Substrate Rugosity Measurements), were not significantly correlated with juvenile densities independent from the habitat use model; the apparently reduced effects of this variable on the densities of juveniles may have been related to the accuracy of the substrate rugosity values in quantifying the appropriate substrate parameters affecting the recruitment process. There was indication (i.e., a non-significant correlation) that juvenile densities during the early substrate associated recruitment period may have been positively correlated with the densities of *Sebastes* from previous cohorts; this is not in agreement with the findings of earlier juvenile rockfish recruitment studies in central Puget Sound (West et al. 1994, West et al. 1995), which indicated that juvenile rockfish avoided habitats occupied by adult rockfishes. There was also indication (i.e., a non-significant correlation) that juvenile densities may have been negatively correlated with the benthic macrophyte coverage of the substrate; this is not supported by habitat use model for BCAR IRH, or other juvenile rockfish recruitment studies in central Puget Sound (Mathews 1988, 1990, West et al. 1994, Doty et al. 1995, West et al. 1995), which established the importance of biogenic habitat to the recruitment process. Any apparent negative effects of macrophyte coverage on habitat use by juveniles, are most likely the result of limitations and inaccuracies in visual surveys in quadrates with abundant benthic macrophytes, which possibly caused artificially lower densities of juveniles through sampling errors.

## Temporal Distributions

A specific objective of this study was too assess the substrate associated recruitment of juvenile copper rockfish and quillback rockfish from the 1991-1994 cohorts, in a variety of natural and artificial reef habitats in northcentral Puget Sound, with regard to temporal distributions of the juvenile rockfishes. The residence time of juvenile quillback rockfish in the bull kelp and macrophyte habitats at GIKM and EKM (1992 cohort, and 1993 and 1994 cohorts, respectively) was too short to detect any ontogenetic distributions. The rapid emigration of the juvenile rockfish with the detached macrophyte habitats appeared to occur irrespective of the sizes of the juveniles.

Surveys of the 1994 cohort of juvenile quillback rockfish on BCAR provided the best information on temporal distributions, which seemed to show movement to deeper habitats with growth. The earliest detected substrate associated recruitment found small-sized recruits (c-y d 54; average 44.8 ± 6.5 mm TL) associated with aggregations of benthic drift macrophytes adjacent to the shallowest (i.e., -3 to -7.6 m MLLW) ARH and IRH substrates. On c-y d 72, the juvenile quillback rockfish found on the IRH central and south habitats, at -7.6 to -9 m MLLW, were larger (i.e., including both juveniles in and outside the survey quadrates; n = 7, average 54.3 ± 5.3 mm TL), and associated with the reef substrate and attached macrophytes. By c-y d 113-115, the juveniles found on the ARH central habitat and the IRH central and south habitats, at -9 to -15 m MLLW, averaged 64 ± 6.6 mm TL. During the period of substrate associated recruitment on the IRH (c-y d 72-113), the depths of the survey quadrates were significantly negatively correlated with juvenile densities. Surveys of the ARH and IRH base habitats on c-y d 121, at -15 to -18 m MLLW, found juvenile quillback rockfish that averaged 80 mm TL. The two juvenile quillback rockfish found on c-y d 323 on the original artificial reef habitat, at -18 m MLLW, were 90 and 100 mm TL.

It is not known how much the apparent increases in the average sizes of the juveniles found in deeper habitats on BCAR may have been related to predation losses of the smallest recruits, or other possible factors that would have resulted in under estimation of the numbers of smaller-sized juveniles on the deeper substrates. The deeper habitats lacked macrophytes on the surfaces of the substrates, which were used by juvenile quillback rockfish as refuge habitat at shallower depths, and this may have resulted in the smaller-sized juveniles seeking refuge deep within the crevices in the rock substrate, and thus being less visible during surveys. Underwater lights were used on deeper habitats to examine crevices for juveniles, so this should not have been a significant source of error, unless there was dramatically different size-related behavior in juvenile quillback rockfish found in the same habitat, at the same depth.

Surveys of the 1994 cohort of juvenile quillback rockfish on GIAR did not provide information on ontogenetic distributions. The ARH and IRH substrates covered only a modest range of depths (-8.8 to -10.7 m MLLW), which confounded detection of any movements of juveniles to deeper habitats with growth. There were also no discernible offshore movements of juveniles, from the (inshore) east habitats to the (offshore) base habitats, which may have indicated that the juveniles were emigrating from the artificial reef recruitment substrates to other deeper habitats. There were no significant differences in the average densities of 1994 cohort juvenile quillback rockfish on the ARH east and base habitats, or on the IRH east and base habitats, and juveniles were not found on the original artificial reef habitat at GIAR.

### Growth and Survival Juveniles

A specific objective of this study was too assess the substrate associated recruitment of juvenile copper rockfish and quillback rockfish from the 1991-1994 cohorts, in a variety of natural and artificial reef habitats in northcentral Puget Sound, with regard to the growth rates and survival rates of the juvenile rockfishes. No other studies have estimated the growth rates of substrate associated juvenile rockfishes in Puget Sound, and there is little information on growth rates for juvenile *Sebastes*. The most recent summary of the ecology of substrate associated juvenile *Sebastes* (Love et al. 1991) does not provide any information on the growth rates of quillback rockfish, and gives only one growth rate for juvenile copper rockfish of 0.15 mm $d^{-1}$ (from Haldorson and Richards 1987). There are four estimates of average growth rates of juvenile copper rockfish, two from this dissertation research, and two from an earlier study; a combination of 1991 and 1994 cohort juveniles from the San Juan Archipelago had an estimated average growth rate of 0.28 mm TL $d^{-1}$, and 1994 cohort juveniles held in aquaria had an average growth rate of 0.33 mm TL $d^{-1}$ (see Chapter 3); 1985 cohort juveniles from the Strait of Georgia had average growth rates of 0.15 mm TL $d^{-1}$ and 0.16 mm TL $d^{-1}$ (Haldorson and Richards 1987), but the accuracy of these estimates are questioned (see Chapter 3).

The 1991 cohort of juvenile rockfishes tagged on BCAR were at least 96% quillback rockfish, and the 1994 cohort surveys on BCAR and GIAR were 100% quillback rockfish; these studies provided the first estimates of juvenile quillback rockfish growth rates during the first cohort-year. The 0.11 mm TL $d^{-1}$ average growth rate of 1991 cohort juvenile quillback rockfish on BCAR from c-y d 117 to 325 (208 d), compares very favorably with the 0.13 mm TL $d^{-1}$ and 0.11 mm TL $d^{-1}$ average growth rates of 1994 cohort juvenile quillback rockfish on BCAR from c-y d 118 to 323 (205 d) and GIAR from c-y d 116 to 335 (219 d), respectively. The surveys of the 1994 cohort on BCAR indicated that this average growth rate was composed of temporal components; an early rapid growth rate of 0.25 mm TL $d^{-1}$ from c-y d 118 to 191 (Oct. 26 to Jan. 7), and a reduced growth rate of 0.06 mm TL $d^{-1}$ from c-y d 191 to 339 (Jan. 7 to June 4). The 1994 cohort juvenile quillback rockfish from BCAR, used to verify species identification in an aquarium grow-out study, also had an early (i.e., c-y d 55-88) rapid average growth rate of 0.25 mm TL $d^{-1}$ under liberal feeding conditions. Temporal components were also noted in the average growth rate of 0.15 mm TL $d^{-1}$ for 1991 cohort juvenile rockfishes (quillback, copper , and brown rockfish combined) on BCAR, over 252 d; a slower growth rate of 0.10 mm TL $d^{-1}$ from c-y d 107 to 320, and a rapid growth rate of 0.38 mm TL $d^{-1}$ from c-y d 320 to 381 (West et al. 1995). The unusually rapid growth rate of 0.38 mm TL $d^{-1}$ from c-y d 320 to 381 includes growth during 15 d in July which is beyond the limit of growth during the first cohort-year (i.e., through June) of this study.

The average growth rates of 1990 cohort juvenile rockfishes held in aquaria in this research, to develop internal micro-tagging techniques (see Chapter 1), were 0.15 mm TL $d^{-1}$ for group Rf 2 (93% quillback, copper, and brown rockfish, combined) over 310 d, and 0.18 mm TL $d^{-1}$ for group Rf 3 (quillback rockfish and copper rockfish) over 132 d. West et al. (1995) noted that the growth rate of group Rf 2 could be divided into the early and late temporal components of 0.10 mm TL $d^{-1}$ from c-y d 124 to 244 (120 d; November-February), and 0.30 mm TL $d^{-1}$ from c-y d 306 to 366 (60 d; May-June). Additional information on temporal components of average growth rates for 1990 and 1991 cohort juvenile rockfishes (i.e., quillback, copper, and brown rockfish, combined) during the first cohort-year in Puget Sound, is available from composite of samples from six natural macrophyte habitats and two artificial reef habitats; the growth rate of 1990 cohort juveniles was 0.46 mm TL $d^{-1}$ from August to October; the growth rates of 1991 cohort juveniles were 0.38 mm TL $d^{-1}$ from July to October, 0.11 mm $d^{-1}$ from October to May, and 0.31 mm $d^{-1}$ from May to July (i.e., to the beginning of the second cohort-year; Washington Department of Fish and Wildlife, unpublished).

The reduced growth rates found for juvenile rockfishes during the November through April period are most likely responses to reduced temperatures, or reduced food availability, or a combination of these environmental parameters. The lowest temperatures in nearshore habitats in central Puget Sound occur during January through April (Mathews 1988), and this is the period when juvenile rockfishes have reduced diurnal activity and remain in crevice habitats in the substrate (see Juvenile Densities and Habitat Use). Temperature has an important affect on growth rates of juvenile rockfishes during the first cohort-year, with warmer temperatures giving higher growth rates, and possibly increased food assimilation efficiency; the combination of these factors may contribute to the first substrate associated recruitment of many juvenile rockfishes to shallower, warmer habitats (Love et al. 1991). Reduced growth of juvenile rockfishes during cooler winter temperatures is supported by the reduced growth rate of the tagging experimental group Rf 2 during November-February, in an aquarium where reduced food availability was not a factor.

The temporal length intervals used in this study to designate juvenile rockfishes during the first cohort-year (see Juvenile Rockfish Temporal Size Ranges), established ≤ 110 mm TL for c-y d 201-365; this was based on the measurement of a 101 mm TL juvenile at c-y d 324, and the survey protocol of rounding visual length estimates up to the next cm interval (see Identification and Enumeration of *Sebastes*). The estimated average growth rate for juvenile rockfishes during the last part of the first cohort-year in Puget Sound nearshore habitats is 0.33 mm $d^{-1}$ (i.e., the average of 0.38, 0.30, and 0.31 mm $d^{-1}$ from the previously referenced studies); using this growth rate, a 101 mm TL juvenile on c-y d 324 would grow to an estimated 114.5 mm TL by c-y d 365. This is in close agreement with the ≤ 110 mm TL interval established for this period.

Previous studies established length intervals of ≤ 80 mm TL for 1986 and 1987 cohort juvenile rockfishes (i.e., quillback, copper, and brown rockfish, combined; Mathews 1988, 1990), and 1991 cohort juvenile rockfishes (West et al. 1994), and ≤ 90 mm TL for 1992 cohort juvenile rockfishes (West et al. 1995), to designate juveniles during the first cohort-year in central Puget Sound habitats. These length intervals were too small to include all juvenile rockfishes in the last part of the first cohort-year, and juveniles longer that these maximum lengths were included in the sub-adult rockfish densities for natural and artificial reef habitats during this period. It is unknown what affect the possible exclusion of larger juvenile rockfishes from average length estimates late in the first cohort-year, may have had on the temporal components of growth rates estimated for this period for the 1990 and 1991 cohorts.

Natural mortality and survival rates parameters have seldom been estimated for juvenile rockfishes during the first cohort-year. The standard methodology for making these estimates for these small-sized fishes was to track the densities in a particular area over time, and this method required assumptions of no emigration, no immigration, and no temporally variable detectability, all of which were difficult to validate. The development of an internal micro-tagging technique to identify groups of juvenile rockfishes in this research (see Chapter 1), theoretically enabled estimates of natural mortality and survival rates without the assumptions of no emigration and no immigration; emigration of tagged juveniles could be monitored on adjacent habitats, and immigration of non-tagged juveniles would not mask losses of tagged juveniles. Temporal variations in detectability could be determined based on increases in the number of tags recovered over time. The development of the tagging technique also enabled "recovery" of the fluorescent tags without physically recapturing tagged fish; this avoided disruptions in normal behavior of the juveniles, and eliminated increased predation-related mortality caused by disturbing the juveniles during capture. Sub-adult and adult quillback rockfish and copper rockfish, and occasionally sculpins, on BCAR and GIAR often responded to juvenile rockfishes attempting to elude capture, by attacking and eating the juveniles (author, personal observation).

The instantaneous rate of loss (i.e., natural mortality and possible emigration) of 0.0106 over 258 d, and the survival rate of 0.9895 for this period, for tagged 1991 cohort juvenile quillback rockfish on BCAR, are the first estimated for this species during the first cohort-year. Additional estimates for natural rates of loss for juvenile quillback rockfish were not possible from the tagged 1992 cohort juveniles in GIKM, or the tagged 1993 cohort juveniles in EKM, because the juveniles rapidly emigrated from these habitats in association with the detached, drifting macrophytes (see Spatial and Temporal Parameters and Recruitment Pathways). The estimate of $Z = 0.0106$ over 258 d for juvenile quillback rockfish on BCAR gives a daily instantaneous rate of loss of 0.000041 $d^{-1}$, or a daily survival rate of 0.999959 $d^{-1}$ (see Data Analyses Methods), which indicates a high survival rate for substrate associated juveniles, at least on artificial reef substrates with abundant refuge habitats. High survival of juvenile rockfishes after substrate association concurs with the findings for two *Sebastes* off the northern California coast, which suggest that year-class strength is determined by the late pelagic juvenile phase (Ralston and Howard 1995).

It is difficult to interpret the levels of the natural loss and survival rate estimates for juvenile quillback rockfish, as the only other mortality rates estimated for juvenile *Sebastes* during the first cohort-year are for juvenile blue rockfish (*S. mystinus*) in nearshore pelagic habitats on the northern California coast. The daily instantaneous "natural mortality" rates for the 1985-1989 cohorts of juvenile blue rockfish during mid-July to April of each cohort year (i.e., c-y d 15-275; 260 d), ranged from 0.001 to 0.008 $d^{-1}$, average 0.006 $d^{-1}$ (Adams and Howard 1996); comparable daily survival rates would range from 0.9990 to 0.9920 $d^{-1}$, average 0.0.9940 $d^{-1}$ (see Data Analyses Methods). The natural loss rate estimates for juvenile blue rockfish are higher than the estimate for juvenile quillback rockfish, but are considerably lower than rates estimated for other juvenile marine fishes (see summary in Adams and Howard 1996); the natural loss rate of juvenile blue rockfish in California coastal ecosystems may be density-dependent, as the "mortality rate" estimates were higher during years with stronger juvenile recruitment (Adams and Howard 1996).

# CHAPTER 3: TEMPORAL AND SPATIAL RECRUITMENT OF JUVENILE *SEBASTES CAURINUS* IN NATURAL HABITATS IN THE SAN JUAN ARCHIPELAGO.

## INTRODUCTION

### San Juan Archipelago

The San Juan Archipelago is a group of about 35 major islands with surface areas of >0.5 km$^2$, and numerous smaller islands, covering an area of approximately 1,760 km$^2$, between 48°25′N at Lopez Island on the south, and 48°47′30″N at Patos Island on the north, and 122°40′W at Cypress Island on the east, and 123°13′30″W at Stuart Island on the west (Figure 3.1). The center of the 21 km south-north, by 22 km east-west, archipelago is approximately 103 km north of central Puget Sound. The archipelago is bounded by the -90 to -290 m mean-lower-low-water (MLLW) depths of the eastern end of the Strait of Juan de Fuca on the south, the southern end of the Strait of Georgia on the north, and Haro Strait on the west, and borders the -55 to -135 m MLLW depths of Rosario Strait on the east.

The central portion of the San Juan Archipelago is dissected by several deep channels, the largest and deepest being the San Juan Channel along the northeastern shoreline of San Juan Island. The tidal currents in the archipelago are predominately strong, and cause extensive mixing of surface and benthic waters at several locations, creating a relatively fertile ecosystem with abundant phytoplankton and zooplankton resources. The net southerly flow in the upper 30 m of water, carries water from the Strait of Georgia, through Haro Strait, San Juan Channel, and Rosario Strait, into the Strait of Juan de Fuca (Anon. 1984).

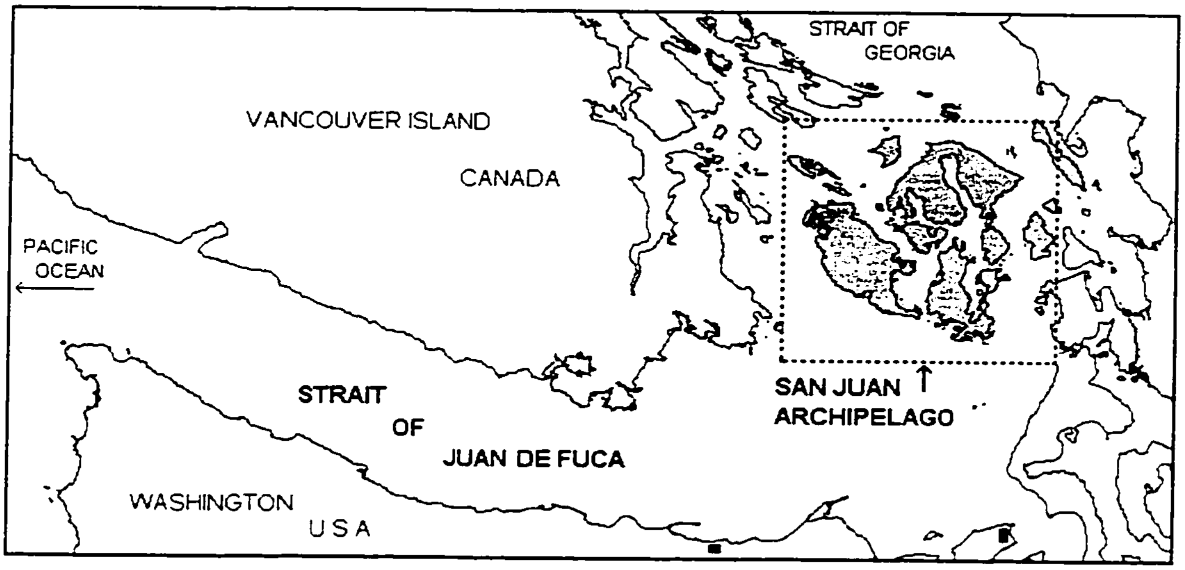


Figure 3.1. Map of the Strait of Juan de Fuca (SJF) and the San Juan Archipelago (SJA).

Considerable freshwater runoff from the Fraser River, entering the southern end of the Strait of Georgia, is carried through the archipelago on these currents.

The shorelines of the islands in the archipelago are predominately rock, typically with rapidly increasing depths in the subtidal rock strata, resulting in narrow bands of nearshore habitat dominated by the canopy-forming, annual macrophyte, bull kelp, *Nereocystis luetkeana*, and understory communities of annual and perennial macrophytes, including *Agarum fimbriatum*, *Laminaria* spp., *Costaria costata*, *Desmerestia* sp., and a variety of folious turf red algae. The macrophyte communities in the archipelago have dynamic seasonal and spatial fluctuations in biomass, resulting from the natural physiology of the plants responding to changes in the ecosystem, which have significant affects on nutrient flow (Duggins and Eckman 1994) and the amount of biogenic habitat available in nearshore ecosystems.

## Juvenile *Sebastes caurinus* Recruitment

The abundant nearshore habitats of rock substrates and attached macrophytes, and benthic rock substrates at deeper depths, in the San Juan Archipelago provide habitat for a number of *Sebastes*. Many of the 20 species of *Sebastes* recorded from the archipelago (Miller and Borton 1980) are found throughout the benthic habitats, and five are known to be in the nearshore macrophyte habitats as juveniles. The most numerous species in nearshore habitats, and shallower benthic habitats, are the sympatric copper rockfish, *S. caurinus*, and quillback rockfish, *S. maliger*.

The substrate associated recruitment of juvenile copper rockfish has not been studied in detail in the San Juan Archipelago. Surveys for juvenile *Sebastes* habitats in 1991 documented (suspected) juvenile copper rockfish in numerous nearshore macrophyte habitats in the southeastern portion of the archipelago (Washington Department of Fish and Wildlife, unpublished), but these surveys were not designed to determine temporal and spatial parameters of recruitment. Similar recruitment pathways for juvenile copper rockfish in macrophyte habitats have been determined in California coastal ecosystems (Anderson 1983, Hallacher and Roberts 1985, Carr 1991), and approximately 102 km north of the central San Juan Archipelago, in an island ecosystem in the Strait of Georgia comparable to the archipelago (Haldorson and Richards 1987). There are no indications from the studies documenting habitat use by copper rockfish, that these recruitment pathways would not be repeated in the archipelago.

In California coastal systems, studies of the 1981 and 1982 cohorts found that pelagic juvenile copper rockfish recruited to the surface macrophyte habitat formed by giant kelp, *Macrocystis pyrifera*, in May, June, and July, as the first substrate association (Carr 1991). The juveniles remained associated with the kelp substrate, and, with ontogenetic development, migrated first to mid-water kelp habitat, and then benthic macrophyte habitat, over monthly intervals. The benthic juvenile copper rockfish were associated primarily with detached drifting macrophytes in the giant kelp beds, until winter storms displaced the drift habitat from nearshore areas. After the loss of the benthic drift habitat, juveniles remained in the nearshore areas, associated primarily with sand/low rock habitat (Carr 1991).

In the cooler ecosystem of the Strait of Georgia, north of the San Juan Archipelago, a study of the 1985 cohort, found that pelagic juvenile copper rockfish recruited in August to the surface habitat formed by fronds of bull kelp, *N. luetkeana*, to the benthic habitats formed by rock substrate and the perennial benthic macrophyte, *A. fimbriatum*, to eelgrass, *Zostera marina*, habitat, and to benthic drift macrophytes, as the first substrate associations (Haldorson and Richards 1987). Juvenile copper rockfish remained associated with the rock and attached macrophyte substrates, and the eelgrass and drift macrophyte substrates, in September and October. The juveniles in the surface frond habitat in bull kelp beds, migrated to the understory macrophyte substrate in September, and remained in this benthic habitat in October.

In the California coastal ecosystem, juvenile copper rockfish were sympatric in the recruitment pathways with the shallow-reef demersal kelp rockfish, *S. atrovirens*, and gopher rockfish, *S. carnatus*. Visual identification of these juveniles was based on gross morphological features and coloration patterns, which was initially difficult when separating early recruited juvenile copper rockfish and gopher rockfish in the kelp frond habitat, at smaller sizes (i.e., <30 mm TL; Carr 1991). In the island ecosystem north of the San Juan Archipelago, juvenile copper rockfish were apparently not sympatric in the recruitment pathways with other juvenile rockfishes, and identification of cohorts was based on size (Haldorson and Richards 1987).

## OBJECTIVES

The general hypothesis of this study was that juvenile copper rockfish utilized similar early substrate associated recruitment pathways in the Washington's non-coastal marine waters, as have been documented for this species in ecosystems to the south and north. Surveys of 1991 cohort juvenile *Sebastes* recruitment habitats in the San Juan Archipelago, tentatively identified the juvenile rockfish in surface kelp frond habitats, and benthic macrophyte habitats, as copper rockfish, based on morphological features, coloration patterns, meristics (of preserved specimens), size, and early recruitment to the kelp frond habitat (Washington Department of Fish and Wildlife, unpublished). Some of these juveniles were maintained in aquaria for 132 d in a micro-tag development study (see Chapter 1; Buckley et al. 1994), and grew to visually identifiable juvenile copper rockfish based on recognized morphological features and coloration patterns (Chen 1986, Matarese et al. 1989); however, these juveniles were mixed with juvenile rockfishes from other areas, forming a group of copper rockfish and quillback rockfish. This made it difficult to confirm that the juvenile rockfish using surface kelp frond habitat and benthic macrophyte habitat recruitment pathways in the San Juan Archipelago, were copper rockfish.

The objectives of this study were to monitor recruitment of substrate associated juvenile rockfishes, early in the cohort-year, in the San Juan Archipelago, (1) to document the temporal and spatial parameters of recruitment of 1994 cohort juvenile copper rockfish in surface and benthic habitats, (2) to confirm identification of the 1994 cohort juvenile copper rockfish through captive grow-out, and (3) to compare the habitat use patterns of the 1991 and 1994 cohorts of juvenile copper rockfish. These objectives would provide the first information documenting substrate associated recruitment pathways of juvenile copper rockfish in Washington's waters.

## METHODS

Visual surveys were conducted in the central San Juan Archipelago to determine the temporal and spatial parameters of the early substrate associated recruitment of 1994 cohort juvenile copper rockfish. These qualitative surveys were conducted starting July 1, 1994 (1) in nearshore bull kelp and benthic macrophyte habitats on the northeast shoreline of Canoe Island (48°33′30″N, 122°55′30″W), on the northwest shoreline of Turn Island (48°32′15″N, 122°58′W), at Fauntleroy Point, Decatur Island (48°31′30″N, 122°47′W), and at Shady Cove, University of Washington, Friday Harbor Laboratories (FHL), San Juan Island (48°32′45″N, 123°30″W), and (2) in nearshore rock substrate and benthic macrophyte habitats on the northeast shoreline of Canoe Island, and on the eastern shoreline at FHL (Figure 3.1). Visual surveys were also conducted in the artificial habitat created by the boat dock pilings, floats, and floating breakwater at FHL.

Visual searches for surface schools of juvenile copper rockfish were conducted from vessels and with snorkeling gear, in randomly selected areas of surface kelp frond habitats. Visual surveys of surface and understory macrophyte habitats in kelp beds, and macrophyte habitats on rock substrate, were conducted underwater using scuba, following random search patterns. Visual documentations of juvenile rockfish recruitment, were followed by collections of the juveniles, using small hand nets with dark red mesh, for length measurements (mm total length - TL), preservation of samples for meristics, and transfer of live samples for captive grow-out identification studies.

The 40 juvenile rockfish (range 18-33 mm TL; average 24.5 ± 3.8 mm TL) used in the grow-out study, were held in research tanks with flow-through sea water systems at the public aquarium in Seattle, Washington, and were fed liberal diets on a daily basis, at rates determined optimal by professional aquarium staff experienced in rearing juvenile rockfishes. The juvenile rockfish were held for 75 d to allow growth and development of recognized morphological features and coloration patterns used in species identifications (Chen 1986, Matarese et al. 1989).

Length data were analyzed using statistical and graphical procedures in Excel 5.0 (Microsoft 1994). Equality of sample means were tested using Analysis of Variance (ANOVA) and the t-test ( Zar 1984). Multiple comparisons of means were tested using the Tukey Honest Significant Difference test (Tukey - HSD test; Zar 1984). Relationships between variables were tested using linear regression (Neter et al. 1990). To facilitate temporal comparisons between cohorts, time was measured on a scale of cohort-year days ( c-y d) for each cohort (see Chapter 2, Table 2.2), which started on July 1 of the settlement year, and ended June 30 of the following year.

## RESULTS

### 1994 Cohort Recruitment and Species Identification

The first 1994 cohort juvenile copper rockfish were found on July 13 (c-y d 13), in various-sized schools, in surface habitats at the FHL boat dock associated with the pilings and moorage float structures, on the eastern shoreline at FHL associated with the upper portions of nearshore *Sargassum muticum*, in the surface habitats of bull kelp fronds at Canoe Island and Decatur Island, and at -4.6 m MLLW in rock and benthic macrophyte habitat on the eastern shoreline at FHL, associated with *Laminaria* sp. The abundance's of juveniles at the FHL locations were visually much greater than in the other survey areas. The small sizes of these juvenile copper rockfish (overall range of 18-34 mm TL; Table 3.1) indicate that this was the first substrate associated recruitment for the 1994

Table 3.1. Substrate associated recruitment of juvenile copper rockfish in the San Juan Archipelago.

| Date | Cohort-year | c-y d[1] | Location[2] | Depth[3] | Habitat[4] |
|---|---|---|---|---|---|
| 7/13/94 | 94 | 13 | San Juan Is. | -4.6 m | rock and macrophytes |
| 7/13/94 | 94 | 13 | San Juan Is. | surface | *Sargassum muticum* |
| 7/13/94 | 94 | 13 | San Juan Is. | surface | Friday Harbor Lab. dock |
| 7/25/91 | 91 | 25 | Burrows Is. | -1 m | rock and macrophytes |
| 8/14/91 | 91 | 45 | Decatur Is. | -6 m | understory macrophytes |
| 9/4/91 | 91 | 66 | Decatur Is. | surface | bull kelp fronds |
| 9/4/91 | 91 | 66 | Decatur Is. | -6 m | understory macrophytes |

| Date | n | Species[5] | Range[6] | Avg ± SD[6] |
|---|---|---|---|---|
| 7/13/94 | 38 | Cr | 18 - 23 | 21 ± 1.6 |
| 7/13/94 | 5 | Cr | 18 - 23 | 20.8 ± 1.9 |
| 7/13/94 | 119 | Cr | 18 - 34 | 25.8 ± 3.6 |
| 7/25/91 | 28 | Cr ? | 27 - 40 | 27.3 ± 4.9 |
| 8/14/91 | 6 | Cr ? | 21 - 37 | 33 ± 5 |
| 9/4/91 | 52 | Cr ? | 20 - 45 | 37.4 ± 4.4 |
| 9/4/91 | 18 | Cr ? | 32 - 58 | 44.4 ± 6.1 |

[1] c-y d = cohort-year day; see Table 2.3.

[2] San Juan Is. = Friday Harbor.

[3] MLLW

[4] rock and macrophytes = rock substrate and benthic macrophytes; understory macrophytes = understory benthic macrophytes in bull kelp habitat.

[5] Cr = copper rockfish; Cr ? = unconfirmed identification.

[6] Total length in mm; Avg ± SD = average length ± standard deviation.

cohort. Juvenile copper rockfish were not found on c-y d 13 in surveys of understory macrophyte habitats (down to - 6 m MLLW) at Canoe Island, or in surveys of surface habitats and understory macrophyte habitats (down to - 6 m MLLW) at Shady Cove and Turn Island.

The average lengths of the 1994 cohort juvenile copper rockfish found on c-y d 13 associated with benthic macrophyte, surface *S. muticum*, and dock substrates at FHL, were significantly different (ANOVA; $F = 37.018$, $p < 0.001$); the average length of the juveniles at FHL dock was significantly greater than in the other habitats (Tukey-HSD test, $\alpha = 0.05$). All three habitats contained 18 mm TL juvenile copper rockfish, which was most likely the smallest size at which the pelagic juveniles became substrate associated, but the juveniles at FHL dock ranged up to 34 mm TL, 11 mm TL longer than the maximum sizes in the other habitats (Table 3.1). The 120 juvenile rockfishes sampled at FHL dock contained one juvenile spiltnose rockfish, *S. diploproa*, which normally recruit to drift macrophyte and seagrass habitats in the San Juan Archipelago (see Chapter 4).

The juvenile rockfish held in aquaria for 75 d (i.e., c-y d 13 to 88) all developed morphological features and coloration patterns characteristic of juvenile copper rockfish (Chen 1986, Matarese et al. 1989).

### 1991 Cohort Recruitment

Surveys for 1991 cohort, substrate associated juvenile rockfishes in the San Juan Archipelago, found juvenile copper rockfish (unconfirmed identifications) in shallow rock substrate and benthic macrophyte habitat at Burrows Island (48°28′30″N, 122°41′30″W) on c-y d 25, in bull kelp bed understory benthic macrophyte habitat at Decatur Island on c-y d 45, and in surface kelp frond habitat and understory benthic macrophyte habitat at Decatur Island on c-y d 66 (Table 3.1). These surveys were not designed to determine the first substrate associated recruitment.

The rock substrate and macrophyte habitat at Burrows island was located in a shallow cove (-1 m MLLW) where there was no immediate access for the juveniles to migrate to deeper depths. The juveniles found in benthic macrophytes at Decatur Island on c-y d 45 and 66 were in the more typical understory habitat at -6 m MLLW, under, and just offshore from, bull kelp beds. On c-y d 66, the juvenile copper rockfish in the surface bull kelp frond habitat at Decatur Island were significantly smaller than the juveniles in the benthic macrophyte habitat at the same location (t-test; $|t| = 5.211$, $p < 0.001$). The small sizes of some of the juvenile copper rockfish on c-y d 25, 45, and 66 (i.e., between 20-27 mm TL; Table 3.1) indicates that early substrate associated recruitment was still occurring on these dates.

### Juvenile *Sebastes caurinus* Growth Rate

Combination of the samples from the 1991 and 1994 cohorts of juvenile copper rockfish found in the southeastern San Juan Archipelago shows a significant linear increase in total length of these groups of juveniles over the period c-y d 13 to 66 (ANOVA; $F = 533.886$, $p < 0.001$; Figure 3.2). This combination of cohorts gives an estimated average growth rate of 0.28 mm TL $d^{-1}$ over these 53 d early in the substrate associated recruitment period.

The 1994 cohort juvenile rockfish from FHL, that were held in aquaria for 75 d (c-y d 13 to 88), grew to an average size of 48.2 ± 7.2 mm TL (length sample

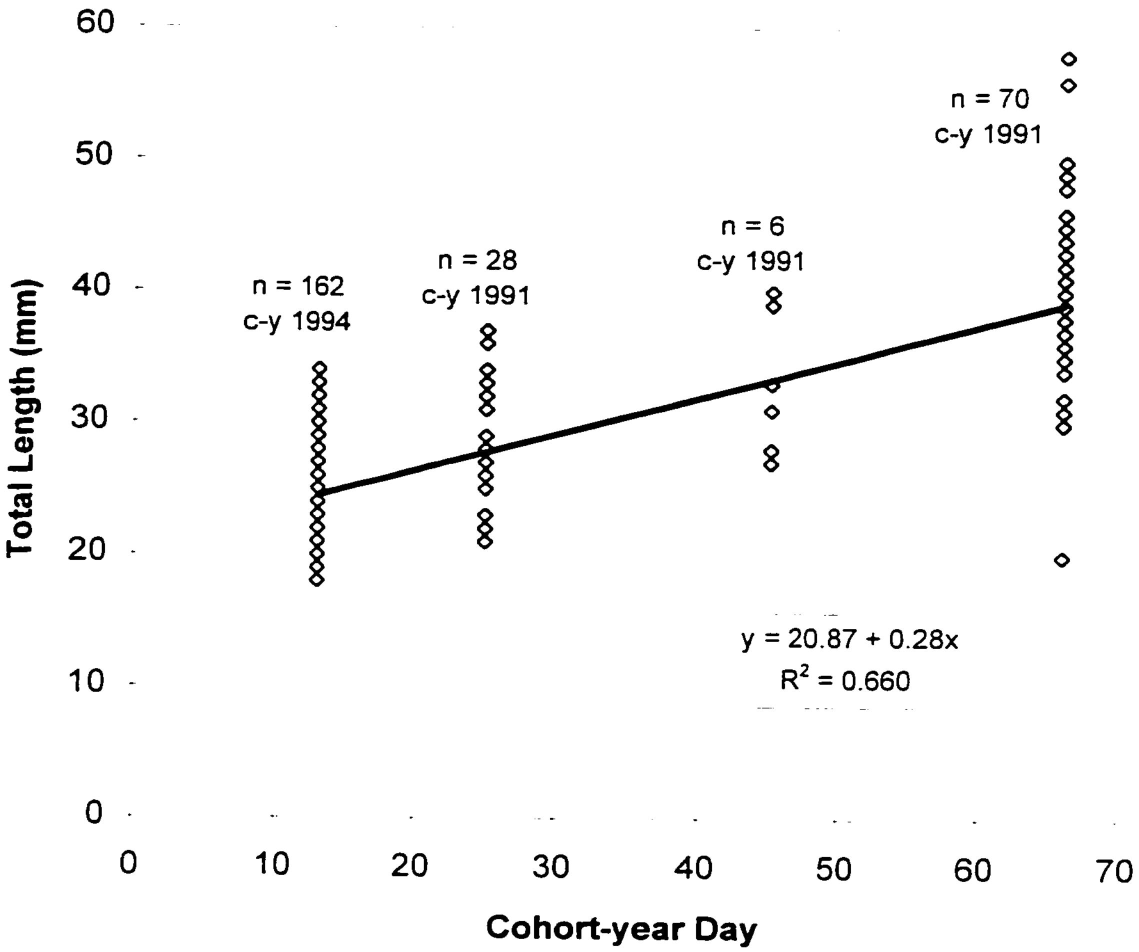


Figure 3.2. Growth rate of substrate associated juvenile copper rockfish in the San Juan Archipelago from c-y d 13 to 66.

size = 25, range 37-60 mm TL). The average growth rate of these captive juveniles was 0.32 mm $d^{-1}$, under optimal feeding and survival conditions.

## DISCUSSION

The early July ( c-y d 13) timing of the first substrate associated recruitment of 1994 cohort juvenile copper rockfish in the San Juan Archipelago, is in agreement with the middle of July to early August (approximately c-y d 15-46) first recruitment timing estimated for juvenile copper rockfish in northcentral Puget Sound (see Chapter 2). This timing was based on surveys of the 1987 cohort (Mathews 1988, 1989), the 1990 cohort (Washington Department of Fisheries, unpublished), and the 1991 cohort (Doty et al. 1995) in this area. The small sizes of the 1991 cohort juvenile copper rockfish found in the archipelago from c-y d 25 to 66 (i.e., July 25-September 4; see Table 3.1), indicates that the single recruitment period can be somewhat protracted in these waters. These temporal parameters for substrate associated recruitment of juvenile copper rockfish also agree with the May through July timing of first recruitment in the lower latitude, warmer waters off California (Carr 1991), and the August timing of first recruitment in the higher latitude, cooler waters of the Strait of Georgia (Haldorson and Richards 1987). These latitudinal differences in the timing for settlement of the pelagic juvenile copper rockfish to substrates, follow the general rule that the principal parturition season for *Sebastes* is shorter and later in northern waters, compared to southern waters (Boehlert 1977; Wootton 1990).

The spatial distribution of the first substrate associated recruitment 1994 cohort juvenile copper rockfish in several types of nearshore habitats in the San Juan Archipelago, indicates a spatial settlement behavior of pelagic juveniles migrating onshore at the surface, and recruiting to the first nearshore substrate encountered at the surface; that is, bull kelp fronds, the tops of *S. muticum*, benthic macrophytes on rock substrate at the tide line, or pilings and moorage floats. This spatial recruitment to shallow habitats is in agreement with surveys of 1987, 1990, and 1991 cohorts of juvenile copper rockfish in central Puget Sound, where early recruits were found in eelgrass, bull kelp frond, and shallow benthic macrophyte habitats (Mathews 1988, 1990, Doty et al. 1995).

Surveys of detached, drifting mats of macrophytes and seagrass in the surface waters throughout the San Juan Archipelago, during the substrate associated recruitment period, have not found any juvenile copper rockfish (see Chapter 4; Buckley et al. 1995). This indicates that juvenile copper rockfish discriminate between nearshore attached macrophyte habitats, and offshore drifting macrophyte habitats, at similar depths. During the recruitment of the 1994 cohort juvenile copper rockfish, some of the drifting habitats were within 50 m of the shoreline at FHL where the juveniles were recruiting. Pelagic juvenile splitnose rockfish are in the surface waters during this same period, and recruit to drifting habitats in large numbers; except for the one 1994 cohort juvenile splitnose rockfish found at FHL dock with the juvenile copper rockfish, this species has never been found in nearshore habitats (see Chapter 4).

The grow-out study of the 1994 cohort juvenile rockfish established that they were copper rockfish, both through the development of morphological features and coloration patterns for juveniles of this species, and through direct comparisons with 1994 cohort juvenile quillback rockfish from BCAR (see Chapter 2) which were in a concurrent grow-out study. The similarities between the timing of recruitment, the recruitment habitats, and the morphological features and coloration patterns of the juveniles of the 1994 and 1991 cohorts in the San Juan Archipelago (see Table 3.1), supports identification of the 1991 cohort as copper rockfish.

Juvenile copper rockfish from several cohorts exhibited similar temporal and spatial habitat use patterns after the first substrate associated recruitment to similar habitats. Juveniles from the 1991 cohort that recruited to bull kelp frond habitat in the San Juan Archipelago, demonstrated a comparatively large size-range that included small-sized recruits (i.e., 20-45 mm TL), indicating that the juveniles remained in this surface refuge and nursery habitat for some time, growing and accumulating new recruits, before migrating to the understory macrophyte habitat. Similar migrations with time and growth have been noted for juvenile copper rockfish recruiting to surface bull kelp frond habitats in central Puget Sound (Doty et al. 1995) and the Strait of Georgia (Haldorson and Richards 1987); it has been documented in Puget Sound bull kelp habitat, that juveniles migrated from the surface frond habitat, to the understory macrophyte habitat, closely associated with the bull kelp stipes (Doty et al. 1995).

Juvenile copper rockfish from the 1994 cohort that recruited to nearshore habitats in the San Juan Archipelago that lacked bull kelp (i.e., rock substrate and benthic macrophytes, or *S. muticum*), appeared to migrate relatively quickly to benthic macrophyte habitats at deeper depths; this is supported by the size-range of the recruits at -4.6 m MLLW that was comparable to recruits in surface habitats. The relatively large numbers and the broad size range of juvenile copper rockfish in the surface habitat at FHL dock, indicates that this habitat accumulated juveniles over time, and that the earliest recruits were not transitioning from the surface habitat, to benthic habitats, in this artificial habitat.

There was considerable disagreement between the average growth rates estimated for juvenile copper rockfish in this study, and those estimated for juveniles in the Strait of Georgia. The combination of the 1991 and 1994 cohorts from the San Juan Archipelago gave an estimated average growth rate of 0.28 mm TL $d^{-1}$ for the period c-y d 13 to 66 (i.e., 53 d; see Figure 3.2). This compared favorably with the 0.32 mm TL $d^{-1}$ average growth rate of the 1994 cohort juveniles from FHL, that were held in aquaria for the grow-out study for the period c-y d 13 to 88 (i.e., 75 d). However, samples of 1985 cohort juvenile copper rockfish in the Strait of Georgia demonstrated average growth rates of only 0.15 mm TL $d^{-1}$ in benthic macrophyte (i.e., *Agarum*) habitat, and 0.16 mm TL $d^{-1}$ in eelgrass habitat, for the period c-y d 46 to 114 (i.e., 68 d; Haldorson and Richards 1987).

The growth rates found in this study for juvenile copper rockfish, are comparable to the growth rate of 0.25 mm TL $d^{-1}$ found for 1994 cohort juvenile quillback rockfish early in the cohort-year, in central Puget Sound (see Chapter 2). The growth rates found in the Strait of Georgia for juvenile copper rockfish, are more comparable to the 0.11 mm TL $d^{-1}$ to 0.13 mm TL $d^{-1}$ found for 1991 and 1994 cohort juvenile quillback rockfish in central Puget Sound, over the majority of the cohort-years (i.e., including the period of reduced rate of growth during the winter months; see Chapter 2). It is unlikely that the 1985 cohort juvenile copper rockfish in the Strait of Georgia experienced slow growth due to reduced food availability, because a concurrent trophic study found that the juveniles were feeding somewhat opportunistically on a variety of benthic and pelagic food items (Haldorson and Richards 1987), similar to juvenile quillback rockfish in nearshore habitats in central Puget Sound (Washington Department of Fish and Wildlife, unpublished). Although the apparently slow rate of growth found for juvenile copper rockfish in the Strait of Georgia could be due to a host of unrecorded environmental parameters and recruitment events, a likely cause may be the method used to collect the samples of juveniles for length determinations. Haldorson and Richards (1987) report collecting juveniles by divers using hand nets, and selecting no more than a few fish from each school of juveniles; this method may have been selective to smaller-sized, more recent recruits, which were more easily captured. Growth rates estimated from juvenile rockfishes collected in this study, and juveniles collected in other studies in Puget Sound (West et al. 1994, Doty et al. 1995, West et al. 1995; see Chapters 1 and 2), were from samples obtained by divers using hand nets, but efforts were made to collect all of the juveniles in the school, or in the area, to avoid potential length-biased capture rates.

# CHAPTER 4: RECRUITMENT OF JUVENILE *SEBASTES* IN NATURAL DRIFT HABITATS IN PUGET SOUND, THE STRAIT OF JUAN DE FUCA, AND THE SAN JUAN ARCHIPELAGO.

## INTRODUCTION

Detached and drifting macrophytes and seagrass are aggregated by internal waves, tidal currents, surface winds, and other oceanographic and atmospheric forces into concentrations, or mats, of habitat in the surface waters (Harrold and Lisin 1989, Kingsford 1992) that provide habitat structure in the open pelagic environment (Kingsford and Choat 1986). Surface slicks from internal waves, frontal zones, and tidal currents also concentrate zooplankton in these areas (Shanks 1988, Franks 1992), creating areas of enhanced biomass. The drift habitat formed by mats of macrophytes and seagrass (hereafter also called drift habitat) are pelagic nursery areas for juvenile fishes, which provide both refuge and abundant food resources, the latter through the invertebrate epifauna on the drift vegetation and the close proximity to concentrations of zooplankton (Kulczycki et al. 1981, Kingsford and Choat 1985, Gorelova and Fedoryako 1986, Wright 1989). Associations of juvenile fishes with algae in temperate marine waters are mostly related to the algae providing enhanced habitat for refuge from predation and for feeding on associated fauna, as there are few herbivorous fishes (Wheeler 1980).

Drift habitat affects the distributions, movements, survivorship, and recruitment patterns of juvenile fishes, through their aggregation from the nekton and colonization of the habitat, and transportation with the habitat (Dooley 1972, Kingsford and Choat 1985, Safran and Omori 1990, Kingsford 1992). Many species of *Sebastes* in the northeastern and northwestern Pacific Ocean recruit from the nekton to drift habitats of detached algae and seagrass (Mitchell and Hunter 1970, Boehlert 1977, Fedoryako 1989, Safran and Omori 1990), and occasionally other flotsam (Hitz 1961), apparently as the first substrate association. Juvenile splitnose rockfish (*S. diploproa*) are found in drift habitats year-around in California coastal waters (Boehlert 1977), and from June through November in non-oceanic waters of Washington (Buckley et al. 1995). In California waters, splitnose rockfish have been shown to undergo transitions from drift habitat to mid-water habitats, possibly for periods up to several months, prior to association with benthic habitats (Boehlert 1977). Some of the time in mid-water habitats may be the result of migration of juvenile splitnose rockfish from drift habitats over deep water, and subsequent horizontal movement to benthic habitats at appropriate depths.

Preliminary studies of drift habitat in the non-oceanic waters of Washington found that this unusual pelagic ecosystem was used as refuge habitat by juvenile splitnose rockfish and tiger rockfish (*S. nigrocinctus.*; Washington Department of Fish and Wildlife, unpublished). A preliminary trophic study examined drift habitat in the San Juan Archipelago during June, August, and October 1992, and found that the juvenile splitnose rockfish fed heavily on the associated epifauna and zooplankton (Shaffer et al. 1995). These studies did not determine if drift habitat was present in this region in other months of the year, or if this habitat was utilized by possibly additional species of juvenile rockfish.

## OBJECTIVES

The importance of the drift habitat ecosystem to juvenile rockfishes in Washington's marine waters was first examined in detail by Buckley et al. (1995).

In this study, Buckley et al. assessed the presence of drift habitat, and juvenile *Sebastes* utilization of this ecosystem, in the Strait of Juan de Fuca, the San Juan Archipelago, and Puget Sound, as part of the Dissertation research presented here. The overall objective for examining drift habitat in these waters was to determine if this habitat was present and used by a variety of juvenile *Sebastes* early in the substrate associated recruitment phase, as a recruitment pathway to nearshore attached macrophyte systems. If drift habitats aggregated nektonic juveniles of nearshore species of *Sebastes*, it would be possible to mark early settlement-stage juveniles with internal micro-tags (see Chapter 1) and track their migrations and movements to other recruitment habitats. The objectives of the assessments of drift habitat and the associated juvenile *Sebastes* were (1) to develop sampling techniques that would allow capture and tagging of juvenile rockfishes, and their release back into the drift habitat, (2) to determine the temporal cycle and macrophyte and seagrass compositions of drift habitats in the Strait of Juan de Fuca, the San Juan Archipelago, and Puget Sound, (3) to determine which species of *Sebastes* aggregated to drift habitat as the first substrate-associated phase of the settlement process, and (4) to define the recruitment pathways of nearshore species of *Sebastes* between drift habitat and attached macrophyte systems.

## METHODS

Sampling of drift habitat was conducted during August and September 1992 in northcentral Puget Sound, and during June 1992 through August 1994 in the Strait of Juan de Fuca (SJF) and the San Juan Archipelago (SJA; Figures 2.1 and 3.1). Samples from June through October 1992, February, June, and August 1993, and August 1994, were made using a dip net with a 2.25 m long handle, a net opening

75 cm long by 35 cm wide, and a 55 cm deep bag of 3.2 mm knotless mesh. Samples from July 1993, September through December 1993, and January through June 1994 were made using a 15.2 m long by 3.7 m deep purse seine of 3.2 mm knotless mesh (after Hunter et al. 1966). Samples from June and July 1994 were made using a 30.4 m long by 7.6 m deep purse seine of 3.2 mm knotless mesh. Both dip net and purse seine samples were made during April through July 1994.

The design of the sampling was intended to detect the presence of drift habitat and associated juvenile *Sebastes* in broad geographic regions. All samples were taken during daylight hours from small vessels. The locations and times of the samples were haphazardly selected, often based on the occurrence of calm weather and tidal conditions. On any sampling day, samples were taken from randomly encountered drift habitats, either working into prevailing tidal currents and winds, or moving considerable distances between samples, to prevent repeated sampling of the same drifting macrophytes and seagrass. Random "non-drift-habitat" dip net samples were also taken in tidal current areas at locations without drifting macrophytes and seagrass, that were at least 5 m from the nearest drift habitat. The sampled drift habitats approximated the range of sizes of habitats (based on visually estimated surface area) that were encountered during a day. For the purse seine sampling during July 1993 to July 1994, a 0.25 $m^2$ floating quadrate, with color-coded markers, was placed on the drift habitat prior to sampling, and the drift habitat was photographed for later projection and tracing of the habitat outline. The habitat surface areas were later digitized from the outline tracings using the 0.25 $m^2$ quadrate as a known reference area.

Visual underwater assessments of the behavior of juvenile rockfishes associated with drift habitats were made to confirm surface observations that the juveniles took refuge within the macrophytes and seagrass when disturbed, usually becoming buried in the tangled vegetation. This behavior ensured that few, if any, juvenile rockfishes escaped the confines of the sampling method.

Dip net samples ranged from entire smaller-sized drift habitats, to only fractions of the volumes of larger-sized habitats. Samples were made by moving the dip net upward through the drifting vegetation to the surface, capturing as much of the macrophytes and seagrass as practical in the net bag. Any large macrophytes extending outside of the dip net were cut free with a knife, when the samples were still outboard of the vessel. Samples were placed in tubs of sea water for careful washing and hand sorting to recover the juvenile rockfishes. Purse seine samples were made by surrounding an entire drift habitat with the net and then pursing the net to capture all the macrophytes and seagrass. A sea anchor was used to hold one end of the net stationary in the water while the vessel circled the drift habitat deploying the remainder of the net.

Large macrophytes were hand sorted, washed and removed from the net outboard of the vessel. The remaining macrophytes and seagrass were placed in tubs of sea water for careful washing and hand sorting. Macrophytes and seagrasses in the samples were identified to the lowest practical taxonomic level. Juvenile *Sebastes* were held for up to two hours in containers of seawater before being identified to species, counted, and total lengths (TL) measured to the nearest mm.

Length data were analyzed using statistical and graphical procedures in Excel 5.0 (Microsoft 1994). Data from normal bivatiate populations were tested for relationships using correlation coefficients (CC; Zar 1984, Neter et al. 1990, Norusis 1993). To facilitate temporal comparisons between cohorts, time was measured on a scale of cohort-year days ( c-y d) for each cohort (Table 4.1), which started on June 1 of the settlement year, and ended May 31 of the following year[11] .

## RESULTS

Both the dip net and purse seine sampling techniques were effective in capturing juvenile *Sebastes* associated with drift habitats, and few of the captured fishes showed any signs of injury or stress, even when held for up to two hours in containers filled with fresh sea water. It is unknown what percentage of the juveniles associated with a drift habitat were captured in the dip net sub-samples of a larger-sized habitat, however, the dip net technique captured 35 juveniles in a sub-sample of a (visually estimated) 9 $m^2$ dense mat of macrophytes and seagrass (August 1992 in SJF). Both the small and large purse seines appeared to capture all of the juvenile *Sebastes* associated with all of the drift habitats sampled with this technique, as the behavior of the juveniles was to seek refuge within the habitat, and not to swim away. The effectiveness of the larger purse seine was demonstrated by the frequent capture of juvenile pelagic fishes (e.g., coho salmon, *Oncorhynchus kisutch*) that were in the vicinity of the drift habitats. Accurate placement of the purse seine around the drift habitats was sometimes impaired by erratic and swirling water motions in areas of strong tidal currents.

The August and September 1992 dip net sampling of drift habitat in northcentral Puget Sound, found five genera of macrophytes and one genus of seagrass, all

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[11] The cohort-year for substrate associated juvenile quillback rockfish and copper rockfish started on July 1 of the settlement year and ended on June 30 of the following year; see Chapter 2, Table 2.3.

Table 4.1. Cohort-year days for substrate associated recruitment of juvenile splitnose rockfish during the first cohort-year.

| | 1992-1994 |
|---|---|
| | c-y d[1] |
| June 1 | 1 |
| June 15 | 15 |
| June 30 | 30 |
| July 1 | 31 |
| July 15 | 45 |
| July 31 | 61 |
| Aug. 1 | 62 |
| Aug. 15 | 76 |
| Aug. 31 | 92 |
| Sep. 1 | 93 |
| Sep. 15 | 107 |
| Sep. 30 | 122 |
| Oct. 1 | 123 |
| Oct. 15 | 137 |
| Oct. 31 | 153 |
| Nov. 1 | 154 |
| Nov. 15 | 168 |
| Nov. 30 | 183 |

| | 1992 | 1993-1994 |
|---|---|---|
| | c-y d[1] | c-y d[1] |
| Dec. 1 | 184 | 184 |
| Dec. 15 | 198 | 198 |
| Dec. 31 | 214 | 214 |
| Jan. 1 | 215 | 215 |
| Jan. 15 | 229 | 229 |
| Jan. 31 | 245 | 245 |
| Feb. 1 | 246 | 246 |
| Feb. 15 | 260 | 260 |
| Feb. 28 | 273 | 273 |
| Feb. 29 | 274 | |
| Mar. 1 | 275 | 274 |
| Mar. 15 | 289 | 288 |
| Mar. 31 | 305 | 304 |
| April 1 | 306 | 305 |
| April 15 | 320 | 319 |
| April 30 | 335 | 334 |
| May 1 | 336 | 335 |
| May 15 | 350 | 349 |
| May 31 | 366 | 365 |

[1] c-y d = cohort-year day.

identifiable to species (Table 4.2). The June 1992 to July 1994 sampling of drift habitat found 12 genera of macrophytes and two genera of seagrasses, 11 identifiable to species, and 10 present in both SJF and SJA samples. All of the 1992 dip net samples contained eight genera of macrophytes and two seagrasses; one species, *Postelsia palmaeformis*, was rare in the drift habitats as it was found in only one sample. Purse seine samples of complete drift habitats in 1993 and 1994 added only four species of macrophytes, including another species, *Pterygophora californica*, found in only one sample (Table 4.2).

The seasonal macrophyte and seagrass composition of drift habitats was quantified in purse seine samples from July 1993 to July 1994 in SJF and SJA (Table 4.3). These samples found drift habitat present in all months in this region, composed primarily of bull kelp, *Nereocystis luetkeana*, giant kelp, *Macrocystis* sp., eelgrass, *Zostera marina* , and rockweed, *Fucus distichus* . The apparent absence of *Macrocystis* during some months reflects a lack of samples in western Strait of Juan de Fuca, the eastern limit of the natural range for this macrophyte. The remaining one genus and seven species of macrophytes, and one genus of seagrass, were present irregularly, in moderate to trace amounts, indicating possible temporal limitations.

The drift habitats sampled in northcentral Puget Sound were structurally loose, and the amount of macrophytes and seagrass in each habitat was sparse, compared to drift habitats sampled in SJF and SJA during the same season. The drift habitats in this region were formed primarily of loose aggregations of eelgrass, *Ulva* sp., rockweed, and a few bull kelp plants; these drift habitats would usually separate and reform in the tidal currents. A total of 37 dip net samples were taken in six locations in northcentral Puget Sound, that have been known historically for

Table 4.2. Macrophytes and seagrasses in drift habitat sampled[1] from June 1992 to July 1994 in the Strait of Juan de Fuca and the San Juan Archipelago (from Buckley et al. 1995).

|  |  | 1992 |  | 1993 |  | 1994 |  | 1992-1994 |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | June-Oct. |  | Feb., June-Dec. |  | Jan.-July |  | Total |  |
| Macrophyte & Seagrass | Code[2] | SJF[3] | SJA[3] | SJF[3] | SJA[3] | SJF[3] | SJA[3] | SJF[3] | SJA[3] |
| *Nereocystis luetkeana* | Nl | X | X | X | X | X | X | X | X |
| *Macrocystis sp.* | Msp. | X |  | X |  | X |  | X |  |
| *Zostera marina* | Zm | X | X | X | X | X | X | X | X |
| *Fucus distichus* | Fd | X | X | X | X | X | X | X | X |
| *Ulva sp.* | Usp. | X |  | X | X | X | X | X | X |
| *Sargassum muticum* | Sm |  | X | X | X | X | X | X | X |
| *Phyllospadix sp.* | Psp. | X |  | X |  | X | X | X | X |
| *Egregia laevigata* | El | X |  | X |  | X | X | X | X |
| *Entermorpha intestinalis* | Ei | X |  | X |  |  | X | X | X |
| *Costaria costata* | Cc |  |  | X |  |  | X | X | X |
| *Desmarestia munda* | Dm |  |  | X |  |  | X | X | X |
| *Postelsia palmaeformis* | Pp | X |  |  |  |  |  | X |  |
| *Alaria nana* | An |  |  | X |  |  |  | X |  |
| *Pterygophora californica* | Pc |  |  |  |  |  | X |  | X |

1] Dip net: June-October 1992; February, June, August 1993; April-July 1994. Purse seine: July, Septemebr-December 1993; January-July 1994.

2] Genus/species code used in Table 4.3 and Figure 4.1.

3] SJF = Strait of Juan de Fuca; SJA = San Juan Archipelago; X = genus/species present in at least one sample.

Table 4.3. Contributions of macrophytes amd seagrasses to drift habitat during July 1993 to July 1994 purse seine sampling - Strait of Juan de Fuca and San Juan Archipelago combined (from Buckley et al. 1995).

|  | 1993[2] |  |  |  |  | 1994[2] |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Code[1] | July | Sep. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | July |
| Nl[3] | 62.1 | 18.2 | 5.3 | 22.7 | 12.8 | 23.4 | 13.3 | 4.3 | 16.5 | 29.3 | 97.5 | 34.8 |
| Msp. | 19 | 50.6 | 0 | 0 | 0 | 356.5 | 0 | 58.2 | 0 | 204.2 | 0 | 0 |
| Zm | 52 | 34.8 | 18.6 | 21.3 | 16.6 | 0.3 | 11.4 | 0.2 | 1.8 | 13 | 36.4 | 29.1 |
| Fd | 13.3 | 9.7 | 19.7 | 4.3 | 0 | 0 | 0.4 | 0 | 6.8 | 28.2 | 29.7 | 47.9 |
| Usp. | 0 | 0.3 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0.3 | 0.2 | 0.4 | 0.1 |
| Sm | 0.9 | 0.2 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 | 0.2 | 0.6 | 1.5 |
| Psp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 |
| El | 0.1 | 0.2 | 0 | 0 | 0 | 0.4 | 0.1 | 0.3 | 0.3 | 0.5 | 0 | 0 |
| Ei | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3 | 0 |
| Cc | 0.1 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.3 |
| Dm | 0 | 1.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.3 | 0 |
| An | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pc | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 |
| n[4] | 7 | 6 | 3 | 3 | 4 | 5 | 4 | 3 | 2 | 3 | 4 | 4 |

1] Genus/species code for macrophytes and seagrasses; see Table 4.2.

2] Average volume in l, except Nl - *Nereocystis luetkeana*.

3} July 1993 - average volume in l; September 1993 to July 1994 - average number of plants.

4] Number of purse seine samples.

tidal current aggregations of macrophytes and seagrass. No purse seine samples were taken in Puget Sound so specific comparisons of total amounts of vegetation cannot be made with other areas. However, historical anecdotal information from Puget Sound recreational and commercial fishermen indicate that the amount of drifting macrophytes and seagrass in this area has decreased dramatically in the last 15 years.

The structure of the drift habitat in SJF and SJA ranged from small clumps of a single species of macrophyte or seagrass (most often rockweed or eelgrass) at the surface, to large, complex, cohering mats of many species, that had three general zones of density and depth (Figure 4.1). The dense surface aggregation (Zone 1) extended to a depth of 0.5 m, and was held together primarily by entangled stipes, pneumatocysts, and fronds of bull kelp and giant kelp, which retained often large amounts of other macrophytes and seagrasses. The moderately dense area under the surface aggregation (Zone 2) extended to a depth of 1.0 to 1.5 m, and was composed of bull kelp fronds and non-floating sections of primarily giant kelp, *Sargassum muticum*, and *Egregia laevigata* that were supported by the vegetation at the surface. The central column of the drift habitat (Zone 3) extended to a depth of up to 3.0 to 4.0 m, and was composed of entangled stipes and holdfasts of bull kelp that were weighted down by benthic material still grasped by holdfasts.

The surface areas of the drift habitats sampled with a purse seine in SJF and SJA, from July 1993 to July 1994, ranged from 0.5 $m^2$ to 27.8 $m^2$. For those drift habitat that were sampled during July to December when juvenile *Sebastes* were in the drift habitat ($n = 27$), there was no correlation between the surface area of the drift habitats and the numbers of juvenile rockfishes in the habitats (CC; $r = -0.082$, $p = 0.686$).

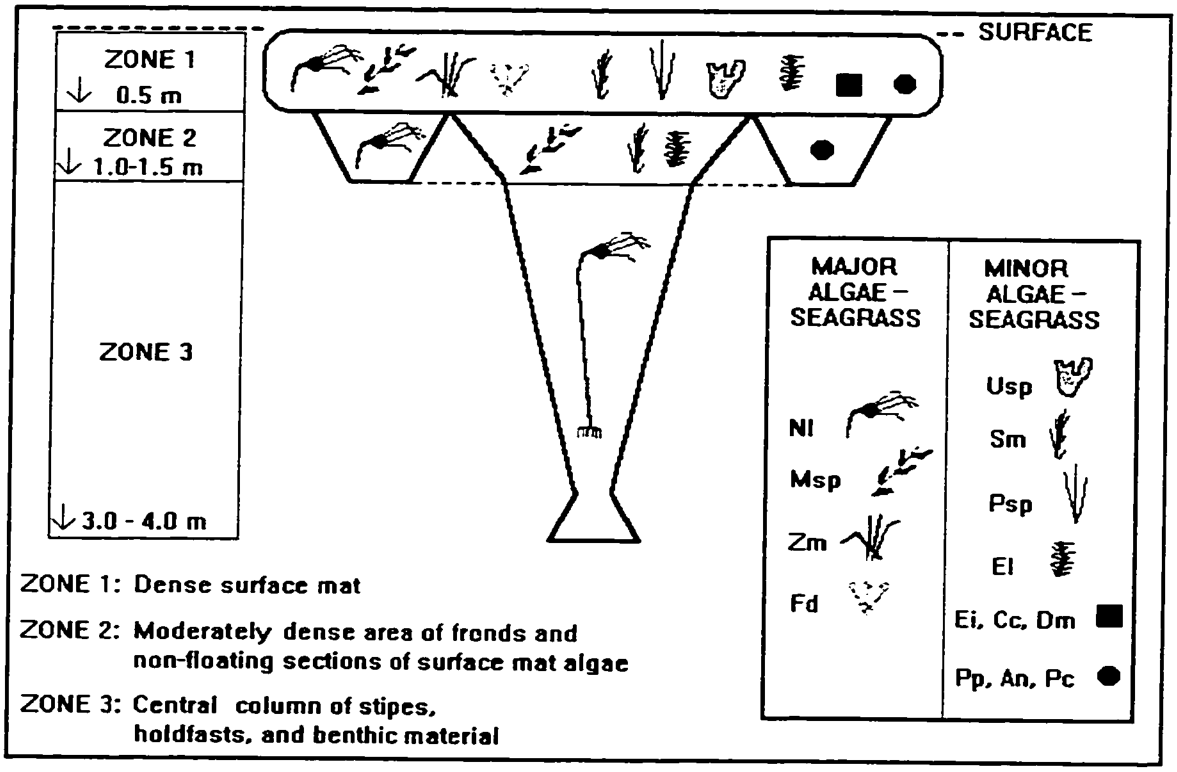

Figure 4.1. Diagram of the structure of complex drift habitat, and the macrophyte and seagrass composition of the three general depth zones (see Table 4.2).

No juvenile *Sebastes* were found in the drift habitats sampled in Puget Sound, and no juveniles were found in the "non-drift-habitat" dip net samples from any of the three regions. Both dip net and purse seine sampling techniques captured juvenile *Sebastes* in drift habitat in SJF and SJA (Table 4.4). Juvenile rockfishes were found in the drift habitat during June and remained in this habitat until November. During these months, dip net samples (n = 179) averaged 3.0 juvenile rockfishes per sample, while the more efficient purse seine samples (n = 28) averaged 22.3 juveniles per sample. Juvenile rockfishes were not found in drift habitat in February 1993, and from December 1993 through May 1994, except for a single fish found in January 1994.

The only species of *Sebastes* found in drift habitats in SJF and SJA were juvenile splitnose rockfish and juvenile tiger rockfish. Splitnose rockfish juveniles comprised 96% (n = 1,123) of the juvenile rockfishes captured in drift habitat in this region (Table 4.5). Substrate associated recruitment of 1992 cohort juveniles, from the nekton to the drift habitat, occurred at 12 to 14 mm TL during c-y d 23 to 81 (i.e., surveys from June 23 to August 20; Table 4.1), and 1993 cohort juveniles recruited to drift habitat at 14 to 15 mm TL during c-y d 29 to 86 (i.e., surveys from June 29 to August 25), indicating protracted recruitment periods for juvenile splitnose rockfish in SJF and SJA. The 13 mm TL juvenile splitnose rockfish found in drift habitat in SJA on c-y d 129 may be an anomaly as the next smallest fish captured in surveys on this c-y d was 19 mm TL (Table 4.5). Splitnose rockfish were present at these small sizes in drift habitat in June 1992 and June 1993, which were the first months sampled in these years, and first appeared in June 1994 in a survey on c-y d 13, when juveniles had not been found during the preceding six months. This indicates that the first substrate associated recruitment

Table 4.4. Frequency of dip net and purse seine samples, and number of juvenile rockfishes, in drift habitat in the Strait of Juan de Fuca and the San Juan Archipelago from June 1992 to August 1994 (from Buckley et al. 1995).

| Date | | n | Gear[1] | Location[2] | Rockfish | | |
|---|---|---|---|---|---|---|---|
| | | | | | Splitnose[3] | Tiger[3] | Total |
| 1992 | June | >3 | DN | SJA | 26 | 1 | 27 |
| | July | 83 | DN | SJF, SJA | 219 | 5 | 224 |
| | Aug. | 43 | DN | SJF, SJA | 177 | 9 | 186 |
| | Sep. | 9 | DN | SJA | 44 | 0 | 44 |
| | Oct. | 6 | DN | SJA | 15 | 0 | 15 |
| 1993 | Feb. | 28 | DN | SJA | 0 | 0 | 0 |
| | June | 12 | DN | SJA | 19 | 7 | 26 |
| | July | 7 | PS | SJF, SJA | 238 | 22 | 260 |
| | Aug. | >1 | DN | SJF | 11 | 2 | 13 |
| | Sep. | 6 | PS | SJF, SJA | 75 | 0 | 75 |
| | Oct. | 3 | PS | SJA | 91 | 0 | 91 |
| | Nov. | 4 | PS | SJA | 193 | 0 | 193 |
| | Dec. | 5 | PS | SJA | 0 | 0 | 0 |
| 1994 | Jan. | 5 | PS | SJF | 1 | 0 | 1 |
| | Feb. | 4 | PS | SJA | 0 | 0 | 0 |
| | Mar. | 3 | PS | SJF | 0 | 0 | 0 |
| | April | 2 | PS | SJA | 0 | 0 | 0 |
| | April | 24 | DN | SJA | 0 | 0 | 0 |
| | May | 7 | PS | SJF, SJA | 0 | 0 | 0 |
| | May | 5 | DN | SJF, SJA | 0 | 0 | 0 |
| | June | 4 | PS | SJF | 5 | 0 | 5 |
| | June | 7 | DN | SJF, SJA | 0 | 0 | 0 |
| | July | 4 | PS | SJA | 0 | 0 | 0 |
| | July | 10 | DN | SJA | 1 | 1 | 2 |
| | Aug. | >5 | DN | SJA | 8 | 0 | 8 |

[1] DN = dip net; PS = purse seine.

[2] SJA = San Juan Archipalego; SJF =Strait of Juan de Fuca.

[3] Splitnose rockfish, *Sebastes diploproa*; tiger rockfish, *S. nigrocinctus*.

Table 4.5. Number and size of subatrate associated juvenile splitnose rockfish sampled in drift habitats in the Strait of Juan de Fuca and the San Juan Archipelago from June 1992 to August 1994 (from Buckley et al. 1995).

| Date | Number | Total Length (mm) | |
|---|---|---|---|
| | | Range | Avg ± SD[1] |
| 1992 June | 26 | 14-42 | 19.8 ± 6.5 |
| July | 219 | 13-47 | 28.3 ± 7.3 |
| Aug. | 177 | 12-51 | 32.5 ± 8.4 |
| Sep. | 44 | 18-47 | 30.7 ± 8.1 |
| Oct. | 15 | 22-41 | 32.5 ± 5.3 |
| 1993 June | 19 | 15-30 | 22.5 ± 4.5 |
| July | 238 | 14-43 | 29.6 ± 7.4 |
| Aug. | 11 | 14-49 | 24.9 ± 9.5 |
| Sep. | 75 | 18-44 | 30.9 ± 7.0 |
| Oct. | 91 | 13, 19-47[2] | 33.0 ± 6.3 |
| Nov. | 193 | 26-48 | 37.7 ± 5.4 |
| 1994 Jan. | 1 | | 44 |
| June | 5 | 17-21 | 19.0 ± 1.4 |
| July | 1 | | 33 |
| Aug. | 8 | 31-51 | 39.3 ± 6.3 |

[1] Average ± standard deviation.

[2] Continuous length frequency distribution from 19-47 mm TL.

of juvenile splitnose rockfish to drift habitat during mid-June in SJF and SJA. The lack of these small sized juveniles after August in 1992 and 1993, combined with monthly increases in the lower ends of the size ranges starting in September of both years (Table 4.5), reflects a recruitment period for juvenile splitnose rockfish of June through August in SJF and SJA.

The average sizes of juvenile splitnose rockfish associated with drift habitats increased from June to October 1992 (i.e., c-y d 23-136), and from June to November 1993 (i.e., c-y d 29-160), indicating the juveniles used the drift habitat as nursery and refuge areas (Figure 4.2; Table 4.5). The average growth rate during 113 d (i.e., c-y d 23-136) in 1992 was 0.11 mm TL $d^{-1}$, and during 142 d (i.e., c-y d 29-171) in 1993 was 0.11 mm TL $d^{-1}$. The maximum sizes of juveniles splitnose rockfish in drift habitats was 51 mm TL in 1992 and 1994, and 49 mm TL in 1993, and appeared to be reached by August in each year ( c-y d 72 in 1992, c-y d 81 in 1994, and c-y d 86 in 1993). These maximum sized fish were not found in samples after August in 1992 and 1993, and there appears to be a general decrease in the maximum size of splitnose rockfish juveniles in drift habitat during later months (Table 4.5). The monthly sampling from June 1992 to August 1994 shows a residence period of June through November for splitnose rockfish in drift habitat in SJF and SJA (Table 4.4).

The start of substrate associated recruitment of juvenile tiger rockfish to drift habitat in SJF and SJA cannot be established accurately as sample sizes were small, however the lack of juveniles in the purse seine samples from September 1993 to June 1994 (Table 4.4) indicates that recruitment earlier than June of the first cohort-year is unlikely. Tiger rockfish juveniles comprised 4% (n = 47) of the juvenile rockfishes captured in surveys of drift habitat during 1992-1994 in SJF and

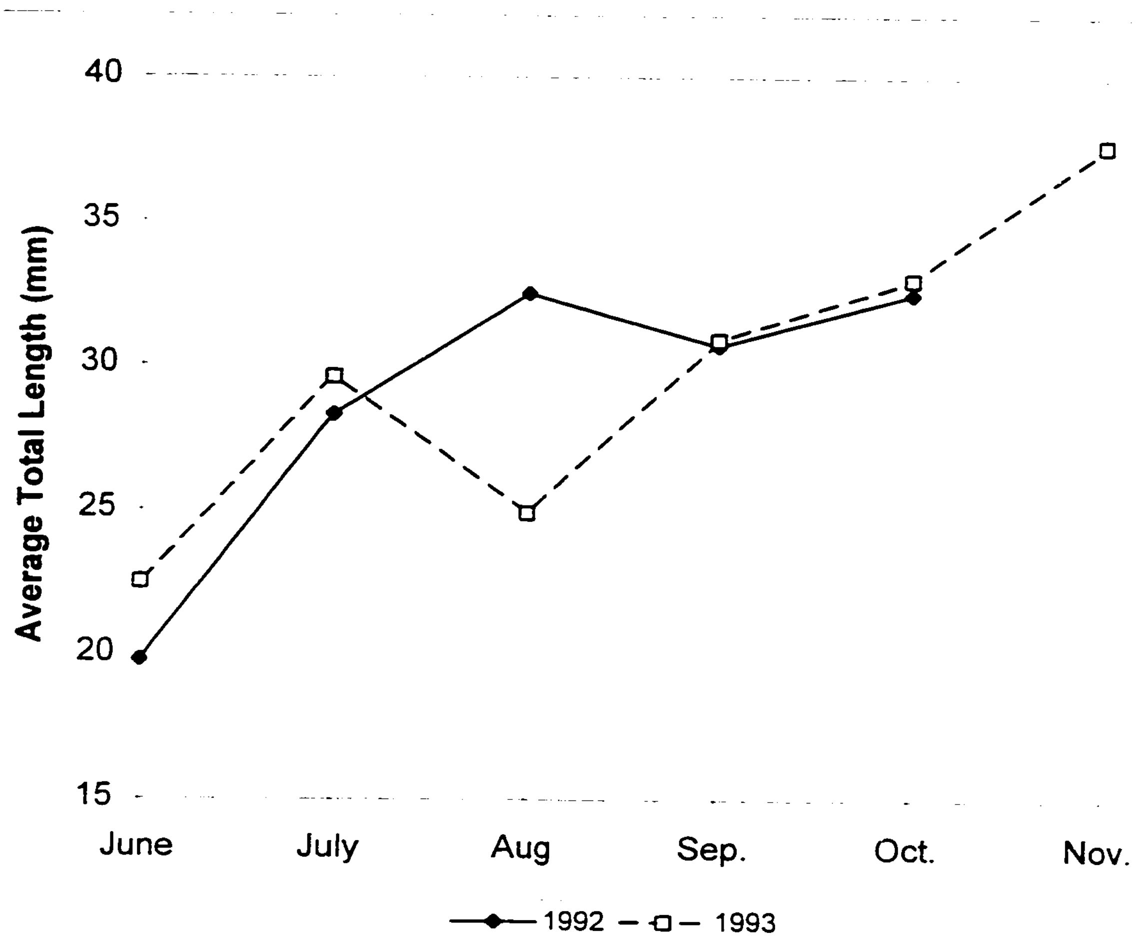

Figure 4.2. Average sizes of substrate associated 1992 and 1993 cohort juvenile splitnose rockfish in drift habitat in the San Juan Archipelago.

SJA (Table 4.6). Substrate associated recruitment from the nekton to drift habitats for this species, appeared to occur at 24 to 28 mm TL, as juveniles were present at this size in the 1992 cohort from June 23 through July 28, and in the 1993 cohort from June 29 through August 25. The estimate of substrate associated recruitment occurring at 28 mm TL indicates a protracted recruitment period of mid-June through August.

The average sizes of 1992 and 1993 cohort juvenile tiger rockfish in drift habitats seemed to increase from June to August, indicating that the juveniles were using the drift habitat as nursery and refuge areas; however, the July 1993 sample of 22 fish provides the only reliable length frequency information (Table 4.6). The largest juvenile tiger rockfish was 53 mm TL, which may be approaching the maximum size reached in drift habitat in SJF and SJA. The residence time for juvenile tiger rockfish in drift habitat appears to be mid-June through August in this region (Table 4.4).

## DISCUSSION

The sampling program was designed to detect the presence of drift habitat and associated juvenile *Sebastes* in broad geographic regions, however, the unstratified sampling, and the use of both dip net and purse seine sampling gear, prevent any detailed inter-annual and inter-regional comparisons of the species of macrophytes and seagrasses in the drift habitats. The dip net was designed to capture juvenile *Sebastes*, and could be used only to note the species of macrophytes and seagrasses present in the dip net samples; most of the drift habitats were too large and physically complex, and many of the macrophytes too large, to be adequately sampled in the 0.7 $m^3$ volume of the dip net. A 71.4%

Table 4.6. Number and size of substrate associated juvenile tiger rockfish sampled in drift habitats in the Strait of Juan de Fuca and the San Juan Archipelago from June 1992 to August 1994 (from Buckley et al. 1995).

| Date | | Number | Total Length (mm) | |
|---|---|---|---|---|
| | | | Range | Avg ± SD[1] |
| 1992 | June | 1 | | 28 |
| | July | 5 | 24-35 | 29 ± 4.2 |
| | Aug. | 9 | 31-53 | 39.7 ± 5.9 |
| 1993 | June | 7 | 27-31 | 28.1 ± 1.6 |
| | July | 22 | 28-47 | 35.2 ± 4.7 |
| | Aug. | 2 | 28-30 | 29.0 ± 1.0 |
| 1994 | July | 1 | | 31 |

1] Average ± standard deviation.

overlap of types of macrophytes and seagrasses (10 of 14) between dip net and purse seine samples during the 1992 through 1994 surveys (Washington Department of Fish and Wildlife, unpublished), indicates that the dip net was sufficiently comparable to the purse seine for capturing and retaining the complex of macrophytes and seagrasses found in drift habitats in SJF and SJA.

Visual tracking of drift habitat in the southern SJA during sampling operations noted that the surface tidal currents in this area appear to facilitate substantial exchanges of drifting material between eastern SJF and SJA, even though the net flow in the upper 30 m of water is southerly, through the SJA into eastern SJF (see Chapter 3). The exchange of drifting material between SJF and SJA is supported by the 10 types of macrophytes and seagrasses common to samples from both areas. The two macrophytes not found in the SJA samples, *Macrocystis* sp. and *P. palmaeforis*, are present as attached macrophytes only in extreme western SJF. Also, winds and prevailing tidal currents throughout SJF create relatively homogeneous surface waters in this region (National Ocean Service 1984). Therefore, samples from SJF and SJA were combined to develop an overall assessment of the temporal cycle, and macrophyte and seagrass composition, of drift habitats in this region.

The spatial dynamics of drift habitat near the entrance of Admiralty Inlet, at the southeastern end of SJF (see Figures 2.1 and 3.1), were not monitored, but the differences in the composition and structure of drift habitat in SJF and Puget Sound indicates that there is little exchange of drift habitat from SJF, into Admiralty Inlet, and ultimately into northern Puget Sound. This is supported by the long-term mean circulation pattern of the two layers of water in Admiralty Inlet and northern Puget Sound; water flows through Admiralty Inlet into Puget Sound in the bottom layer, and out of Puget Sound through Admiralty Inlet in the top layer (Cokelet et al. 1991). Although large tidal exchanges transport some of the surface water in Admiralty Inlet into Puget Sound, the net flow in the upper 30 m of water is out of Puget Sound (McGary 1977, Anon. 1984). Also, flooding-tide counter-currents and gyres along the shorelines at the north end of Admiralty Inlet (McGary 1977) tend to trap surface water and associated drifting material in this area, further reducing the potential exchange of drift habitat from SJF into Puget Sound.

The 1993 and 1994 sampling confirmed that drift habitats were present in SJF and SJA throughout the year, and that there was little variation in the macrophyte and seagrass composition of the habitat. The composition of the macrophytes and seagrasses in the drift habitats were quantified in the purse seine samples, although, the distribution and frequency of this sampling was inadequate for refined assessments of any spatial and temporal variations in the abundance macrophytes and seagrasses. Bull kelp, giant kelp, eelgrass, and rock weed formed an estimated 98 to 100% of the volume of drift habitats throughout the 1992 to 1994 surveys (see Table 4.3).

Dip net and purse seine samples captured the same size ranges of juvenile *Sebastes* in drift habitats (see Tables 4.5 and 4.6), therefore both types of data were combined for inter-annual comparisons of substrate associated recruitment ecology in drift habitats. The small number of juvenile rockfishes captured during June through August 1994 (n = 15) with substantial sampling effort (22 dip net and 8 purse seine samples), compared to the large numbers of juveniles captured during June through August in 1992 (n = 437) and 1993 (n = 299), indicates that substrate associated recruitment of juvenile splitnose rockfish (96% of total) was considerably stronger for the 1992 and 1993 cohorts, than for the 1994 cohort in

SJF and SJA. It is not known if these apparent variations in cohort strength are part of a normal cycle, or if it is an artifact of later recruitment of the 1994 cohort, that may have been missed by cessation of sampling in August.

The failure to find any splitnose rockfish in the minimal drift habitat in northcentral Puget Sound, may have been due to (1) the limited spatial and temporal sampling of drift habitat in this area, (2) the lack of exchange of drift habitat from SJF into Puget Sound, (3) low recruitment of the 1992 cohort of juvenile splitnose rockfish in Puget Sound, or (4) simply the lack of splitnose rockfish in this region. Splitnose rockfish are apparently uncommon in Puget Sound (Miller and Borton 1980). It cannot be determined from this study if juvenile splitnose rockfish recruit to drift habitat in Puget Sound, or if juveniles may use an alternative recruitment pathway during the first substrate associated recruitment in this ecosystem.

Substrate associated recruitment of juvenile splitnose rockfish to drift habitats in SJF and SJA during June through August, and the residence time of juveniles in this habitat from June through November in this region, differs from the ecology of this species in drift habitat in southern California waters. In California's warmer oceanic ecosystem, juvenile spiltnose rockfish recruited to drift habitat (primarily *M. pyrifera*) during February through March, and July through December, and were present in drift habitat in all months (Boehlert 1977). The size of these juveniles at recruitment from the nekton to the drift habitat was 10 to 15 mm standard length (SL; approximately 12 to 18 mm TL; Washington Department of Fish and Wildlife, unpublished), which is comparable to the 12 to 15 mm TL recruitment size found in Washington's waters in 1992 and 1993 (Table 4.5).

Juvenile splitnose rockfish apparently settle from the drift habitat, to adult benthic habitats at 91 to 578 m depths (Hart 1980), throughout their range (Boehlert 1977). In California waters, this migration appears to occur at 41 to 49 mm SL (approximately 47 to 57 mm TL) primarily during May and June, however juveniles of settlement-size are present throughout the year (Boehlert 1977). In SJF and SJA, migration from surface drift habitats to (apparently) deeper water habitats appears to occur primarily at >49 to 51 mm TL, during August through November; however, the disappearance of juvenile splitnose rockfish from drift habitats after November, when 26 mm TL juveniles were present, indicates that this migration also occurs at much smaller sizes (see Table 4.5). Based on the general rule that the principal parturition season for *Sebastes* is shorter and later in northern waters compared to southern waters, Boehlert (1977) anticipated that in northern waters the residence time of juvenile spiltnose rockfish in drift habitats would be more distinct, and the migration from surface waters would be more precise. This is verified by the timing found in the more northern waters of SJF and SJA, although migration in this region must also be cued by one or more environmental parameters (i.e., season, temperature) in addition to body size, or there would be progressive growth of the smaller juveniles in the drift habitat in November to the migration size.

The growth rate of juvenile spiltnose rockfish in California waters was estimated as 0.19 mm SL $d^{-1}$, and was found to increase from 0.11 to 0.16 mm SL $d^{-1}$ with a temperature increase of 10 to 15° C under laboratory conditions (Boehlert 1981). The growth rate of 0.11 mm TL $d^{-1}$ for juvenile splitnose rockfish in the colder waters of SJF and SJA may be expected to be lower, but it seems to indicate another parameter other than temperature, possibly trophic or metabolic energy needs, may be affecting growth rates in this region. The maximum size of the juveniles found in drift habitat in California, 55 mm SL (approximately 63 mm TL), was also considerably larger that the maximum of 51 mm TL found in Washington waters.

Drift habitats in SJF and SJA function as nursery and refuge habitats for substrate associated juvenile splitnose rockfish. Drift habitat in this region also apparently functions as an intermediate recruitment pathway to deep water pelagic and benthic habitats for juvenile splitnose rockfish, if juveniles disappear from the drift habitat due to migration, and if they follow recruitment pathways similar to those detected for this speices in California waters (see Bohlert 1977). It is speculation that juvenile splitnose rockfish migrate from drift habitats, as opposed to seasonal losses due to mortality, and that the juveniles survive to reach benthic habitats after leaving the drift habitats, as the adults of this species have not ben verified in benthic habitats in this region. However, it is equally possible that drift habitat is more than just a functional recruitment habitat of opportunity for juvenile splitnose rockfish in SJF and SJA, and is instead a vital, or maybe even an obligate, juvenile recruitment habitat for this species.

Drift habitats in SJF and SJA function as nursery and refuge habitats for substrate associated juvenile tiger rockfish. Due to the small sample sizes for juvenile tiger rockfish, it is unclear if drift habitat is important to recruitment for this species, or if it is just a habitat of opportunity, perhaps even reducing ultimate survival by displacing juveniles into inappropriate habitats.

The numbers of juvenile *Sebastes* captured in drift habitat using dip net and purse seine techniques, and their high survival after capture, indicates that this would be a good methodology for tagging and releasing juvenile rockfishes in this ecosystem.  However, this study establishes that drift habitat in Juan de Fuca

Strait and the San Juan Archipelago is not used by a variety of juvenile *Sebastes* as an early recruitment habitat pathway to nearshore attached macrophyte systems. The only possible exception is that juvenile tiger rockfish, which are a relatively nearshore species of *Sebastes* (Hart 1980), may be transported to favorable nearshore areas by drift habitat that remains relatively close to the shoreline.

# CHAPTER 5: SUMMARY AND DISCUSSION

*Sebastes* are an important complex of fishes in Puget Sound and the San Juan Archipelago. The ecological importance of *Sebastes* in these waters, although inadequately researched, must be substantial, as many species are abundant in nearshore habitats from juvenile to adult life stages, and *Sebastes* are known to be both piscivorous and invertebrate predators, as well as prey for other fishes and piscivorous birds. Many *Sebastes* also have long been targets of recreational and commercial fishery harvests in this region, with eight species designated as "management species" (Pedersen and DiDonato 1982) and their harvests monitored and regulated in fishery management programs. Harvests of *Sebastes* in Puget Sound and the San Juan Archipelago have been primarily in recreational fisheries in recent years, and the trend in fishery management has been to reduce daily harvests limits based on declining harvest rates, and declining mean lengths of key species in the harvests, both of which signal possible over-harvest or other conditions of population stress (Palsson et al. 1996).

The primary source of mortality for substrate associated juvenile rockfishes during the first cohort-year appears to be predation by a range of piscivorous fishes and birds; it is generally accepted that juvenile rockfishes in nearshore habitats are normally not food limited (Love et al. 1991). The primary fish predators of juvenile rockfishes in natural and artificial reef habitats in central Puget Sound remain unknown, however, it is likely that they include lingcod and a variety of sculpins (see Ecological Importance of *Sebastes*). It has been speculated that cannibalism and intra-generic predation are also sources of mortality for juvenile rockfishes in these habitats, but this remains undocumented to any extent (see Cannibalism and Other Predation), except in unusual situations when larger-sized *Sebastes* become “circumstantial piscivores” (see Hixon and Beets 1993; e.g., when juveniles are fleeing capture) and feed on juveniles. If the sub-adult and adult quillback rockfish and copper rockfish on artificial reef habitats were predators on juvenile rockfishes, it appears that they would have been large enough to have consumed most of the juveniles (see Appendix VI); 150 mm TL quillback rockfish and copper rockfish consume fish prey that average 68 mm TL (Murie 1991). Even if the larger rockfishes were predators on juvenile rockfishes only occasionally, or circumstantially, their often high abundance’s on BCAR and GIAR (see Table 2.11) could account for significant juvenile rockfish mortalities on artificial reef habitats. In contrast, few sub-adult and adult quillback rockfish and copper rockfish were noted in GIKM, MKM, and EKM concurrent with juvenile rockfishes.

The stocks of many *Sebastes* in Puget Sound and the San Juan Archipelago appear to be declining, apparently in response to anthropogenic stressors. The continual and increasing urbanization-related impacts to nearshore habitats used by *Sebastes* during the juvenile substrate associated recruitment period are potentially significant stressors. Basic ecological information is needed on recruitment of juvenile *Sebastes*, in order to develop methods to aviod or offset losses of juvenile recruitment habitats, and to advance the management and enhancement of *Sebastes* resources in these waters. Significant contributions to these information needs would result from (1) determining the recruitment habitat pathways of juvenile *Sebastes*, and other ecological parameters important during substrate associated recruitment, that contribute to successful natural production, and (2) determining the potential for enhancing natural recruitment of juveniles in local nearshore habitats, by using specially designed artificial reefs to increase the amount of recruitment habitat.

## OVERALL OBJECTIVES

There were two overall objectives for the Dissertation research presented here, which were in response to the need for ecological information on the processes affecting natural production of *Sebastes* resources in nearshore habitats in the non-oceanic waters of Washington:

I. To clarify the ecology of substrate associated recruitment by copper rockfish (*S. caurinus*), quillback rockfish (*S. maliger*), and splitnose rockfish (*S. diploproa*) in macrophyte habitats, and in natural and artificial rocky reef habitats, in northcentral Puget Sound and the San Juan Archipelago.

II. To determine if manipulating artificial rocky reef substrates in northcentral Puget Sound, to simulate natural habitats used by juvenile copper rockfish and quillback rockfish during substrate associated recruitment, would enhance local natural recruitment and survival of these species.

## JUVENILE *SEBASTES* RECRUITMENT PATHWAYS

Relatively little is known about the ecology of larval and pelagic juvenile *Sebastes*, and even less is known about these life-stages for most species due to identification difficulties. Larval quillback rockfish have not been described (A. Kendall, Jr., NOAA/NMFS Alaska Fisheries Science Center, Seattle, WA, personal communication), and identification of the pelagic juvenile stage remains uncertain (Kendall 1991). It is assumed that quillback rockfish have a pelagic juvenile life-stage, as this is common throughout *Sebastes*, but it is unknown if the pelagic juveniles are found in surface, or mid-water, or demersal habitats. Larval and pelagic juvenile copper rockfish and splitnose rockfish have been described (Kendall 1989, 1991), and there is some information on the ecology of these life-stages; pelagic juveniles are in surface waters, at least late in the pelagic juvenile phase for copper rockfish (Moser and Boehlert 1991). The inadequately defined parameters for pelagic phases of *Sebastes* make it difficult to understand and anticipate the inter-annual temporal and spatial variability common in early post-pelagic phases.

The transitions of juvenile *Sebastes* from pelagic juveniles to substrate associated juveniles, is a critical period of changes in a host of biotic and abiotic factors affecting juvenile survival. The substrate associated juveniles continue to transition through a variety of nursery and refuge habitats with growth and development. The quality and quantity of these nursery and refuge habitats affects the success of the cohort. Obtaining information on the recruitment pathways of substrate associated juveniles is difficult for many species, because the complex biogenic habitats and benthic substrates used by juveniles confound accurate sampling. In addition, *in situ* identification difficulties have resulted in many studies reporting on species complexes of substrate associated juvenile *Sebastes*, eliminating species specific information.

Juvenile copper rockfish recruitment has been studied in several ecosystems outside of Washington waters (e.g., Anderson 1983, Hallacher and Roberts 1985, Haldorson and Richards 1987, Carr 1991), providing valuable information for this species. However, the most recent review of substrate associated recruitment of juvenile *Sebastes* (Love et al. 1991) reports that there is “no data” to describe the characteristics of the recruitment habitat for juvenile quillback rockfish. Earlier studies of substrate associated recruitment of juvenile quillback rockfish and copper rockfish in Puget Sound have limited value, because these species were combined in a complex with brown rockfish, *S. auriculatus*. The Dissertation research presented here has verified the substrate associated recruitment habitats of juvenile quillback rockfish in Puget Sound, and juvenile copper rockfish in the San Juan Archipelago, using grow-out studies for accurate species identifications (see Chapters 2 and 3). This research also presents the first information on the substrate associated recruitment of juvenile splitnose rockfish to surface drift macrophyte and seagrass habitats in the San Juan Archipelago and the Strait of Juan de Fuca (see Chapter 4; Buckley et al. 1995). A common finding for these three species in local temperate waters, is distinct spatial partitioning of the recruitment habitat substrates, and there appears to be distinct substrate associated recruitment habitat selection between pelagic juvenile copper rockfish and splitnose rockfish.

## Recruitment of Juvenile *Sebastes maliger*

### Model of Spatial and Temporal Parameters

Repeated surveys of a variety of nearshore habitats in northcentral Puget Sound, during the first part of the 1994 cohort-year, found that the first substrate associated recruitment in nearshore habitats, for 1994 cohort juvenile quillback rockfish in this area, was on benthic macrophyte substrates in late August (c-y d 59; i.e., cohort-year day, see Table 2.2). Length frequency information for juvenile rockfishes from the 1991 through 1994 cohorts in central Puget Sound, confirmed that juvenile quillback rockfish have a single recruitment period each cohort year. Documentation of the earliest (c-y d 54), smallest-sized, 1994 cohort juvenile quillback rockfish in association with benthic drift macrophytes on nearshore sand habitat, lead to the theory that juvenile quillback rockfish first recruited to offshore benthic habitats, and migrated onshore with time and growth. This theory was supported by the larger-sizes of the first 1994 cohort juvenile quillback rockfish found on nearshore benthic macrophyte substrates.

The following model of spatial and temporal recruitment parameters and pathways, for the early phases of substrate associated recruitment of juvenile quillback rockfish in Puget Sound, is based primarily on information presented in Chapter 2 of this Dissertation research (Figure 5.1):

- I. Pre-settlement pelagic juveniles are (possibly) in offshore mid-water habitats, moving onshore in the late pre-settlement stage; prior to July (<c-y d 1).

This speculation is based on the abundance of quillback rockfish in Puget Sound and contiguous waters, but the lack of this species in descriptions of larval and pelagic juvenile stages, which are based mainly on plankton net and neuston net collections at the surface, and plankton net collections in the upper water column. Pelagic juveniles of most of the common *Sebastes* have been described, except those species that do not have an extensive pelagic juvenile stage (Kendall 1991), or the pelagic juvenile stage is infrequently, or ineffectively, encountered by sampling methods. *Sebastes* juveniles are common at deeper depths, but usually are found above 100 m; there is evidence that some pelagic juvenile *Sebastes* use midwater depths as pre-recruitment habitat (Moser and Boehlert 1991).

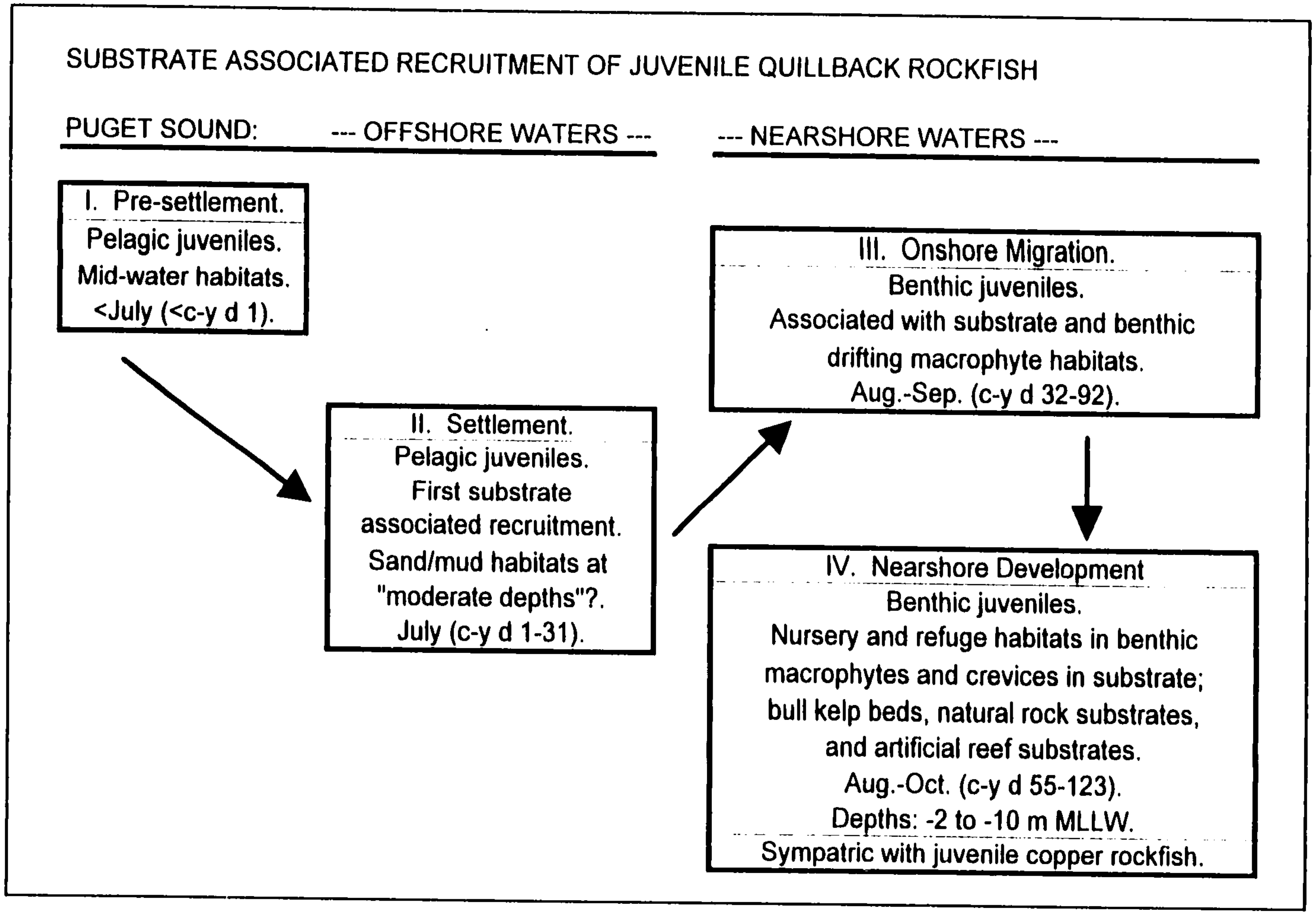

Figure 5.1. Model of spatial and temporal parameters and pathways for early substrate associated recruitment of juvenile quillback rockfish in Puget Sound.

The timing of the pelagic juvenile stage is related primarily to the timing of parturition; parturition in quillback rockfish is inferred from maturity studies in other areas, and is thought to occur earlier in the southern end of the range of the species, but has never been documented for Puget Sound. Captured quillback rockfish extruded larvae during May-July off Alaska, and during April-July off California (from Wyllie Echeverria 1987), indicating that parturition may occur in Puget Sound as early as April or May. This speculation is based on the information available, and the proposed early July timing for first substrate association for juvenile quillback rockfish, which seems compatible with the inferred parturition season. This is difficult to confirm, because the parturition habitat for quillback rockfish has never been documented; however, fish extruding viable embryos were caught in deep water, in April, in central Puget Sound (Washington Department of Fish and Wildlife, unpublished). The duration of the larval and pelagic juvenile periods for quillback rockfish are unknown, but there are indications of considerable inter-annual variability in the durations of these life-stages in *Sebastes*.

- II. Pelagic juveniles may settle to offshore sand or mud substrates, possibly having some biogenic structure, at moderate depths, as the first substrate associated recruitment; July (c-y d 1-31).

Although this is presently speculation, it is supported somewhat by the lack of small-sized, early substrate associated juvenile rockfishes in surveys of other, ecologically relevant, nearshore benthic and surface habitats. It is noteworthy that the pelagic juveniles of at least one other nearshore rocky reef fish in Puget

Sound, the lingcod (*Ophiodon elongatus*), first recruit to open sand habitat and later migrate to more typical habitat for the species (Buckley et al. 1984).

The timing of the first substrate associated recruitment of juvenile *Sebastes* is, in part, related to the size of the pelagic juveniles. Pelagic juvenile *Sebastes* range from about 15 to 50 mm standard length (SL), and benthic juveniles from about 20 to 70 mm SL, depending upon the species (Kendall 1991). Juvenile quillback rockfish in Puget Sound must make the transition from pelagic to benthic habitats at least by 30 mm TL, as a 31 mm TL 1994 cohort juvenile was found associated with nearshore benthic drift macrophytes on August 24 (i.e., c-y d 55). The average size of these juveniles found on c-y d 55 was 44.8 mm TL, and, subsequently, these juveniles had an average (significant linear) growth rate of 0.25 mm $d^{-1}$ under liberal feeding conditions. Assuming that pelagic juvenile quillback rockfish recruited at 30 mm TL, and the juveniles grew at 0.25 mm $d^{-1}$, it would take about 59 d to reach the average size of the juveniles on c-y d 55. This lends support to the theory that the first substrate association for 1994 cohort juvenile quillback rockfish occurred, presumably in offshore habitats, in late June or early July (i.e., about c-y d 1).

- III. Juveniles appear to migrate onshore with time and growth, in association with the benthic substrate, or aggregate with benthic drifting macrophyte substrate, to nearshore benthic macrophyte habitats in bull kelp (*Nereocystis* luetkeana) beds, on natural rock substrates, and on artificial reef substrates; August and September (c-y d 32-92); juveniles seldom migrate to eelgrass (*Zostera marina*) habitat.

This possible pathway and timing for recruitment is supported by finding the earliest, smallest-sized juveniles (i.e., August; as small as 31 mm total length - TL, average 46 mm TL) associated with benthic drift macrophyte habitat on nearshore sand substrate at six locations, when juveniles were not found in surveys of adjacent attached benthic macrophyte, rocky reef, artificial reef, and eelgrass habitats. Juveniles found later in attached benthic macrophyte habitats were considerably larger (i.e., September and October; average 58-60 mm TL).

- IV. Juveniles use the benthic macrophytes and crevices in the rock substrates, in bull kelp beds, natural rock substrate, and artificial reef substrate, as nursery and refuge habitat; depths from -2 to -10 m MLLW; juveniles are sympatric with juvenile copper rockfish; late August through October (c-y d 55-123).

## Corrections to Errors in Recruitment Parameters

A previous study of 1987 and 1988 cohort juvenile rockfishes (copper, quillback and brown rockfish, combined) in central Puget Sound (Mathews 1988, 1990), reported spring and fall settlement periods for, assumed to be primarily, juvenile quillback rockfish on the original reef substrate at BCAR ( Boeing Creek Artificial Reef). This study also reported that juvenile rockfish were found year-around on BCAR at 15-20 m depths (depth corrections to MLLW not indicated). This study speculated that the spring settlement period for juvenile quillback rockfish was either (1) the result of two reproductive (i.e., parturition) periods for quillback rockfish in Puget Sound, or (2) caused by a pulse of recruits arriving at BCAR from northern Puget Sound, the Strait of Juan de Fuca, or outer coast areas.

It is clear from the results of the Dissertation research presented here, that the spring settlement periods described for 1987 and 1988 cohort juvenile quillback rockfish at BCAR by Mathews (1988, 1990) were not valid, and were based on incorrect identification of juvenile Puget Sound rockfish (*S. emphaeus*), as juvenile quillback rockfish. The 1990 cohort juvenile Puget Sound rockfish used as group Rf 1 in the study to develop micro-tagging techniques for *Sebastes* (see Chapter 1), were collected in August on BCAR, at -16 to -18 m MLLW, on the northern permanent transect line used in the study of the 1987 and 1988 cohorts. The 1990 cohort juvenile Puget Sound rockfish were very abundant at this location, equaling the 1.25 fish $m^{-2}$ reported for the 1988 cohort juvenile rockfish on BCAR in April (Mathews 1990). The identification of the Puget Sound rockfish was verified by (1) the early spring settlement of juveniles to rocky substrates at 12 to 15 m depths (Moulton 1975), (2) definitively high gill raker counts and other meristic characteristics (Chen 1986, Matarese et al. 1989), (3) fairly distinctive juvenile pigment patterns (Matarese et al. 1989), and (4) a 330 d grow-out study as part of the tests for micro-tag retention (see Chapter 1).

Sub-adult Puget Sound rockfish may also have been incorrectly identified as part of the complex of juvenile rockfishes (copper, quillback, and brown rockfish combined) used in the study of the 1987 and 1988 cohorts on BCAR. Adult Puget Sound rockfish reach a maximum reported length of only 179 mm (Moulton 1975), and the growth rate for this species is only 0.08 mm TL $d^{-1}$ (see Chapter 1); this indicates that sub-adults of this species could have been within the size criteria of <80 mm TL used for juveniles, and mistaken for juveniles of the complex of rockfishes, during the first cohort-year (see Mathews 1988). There are indications that previous investigators had mistaken the small-sized Puget Sound rockfish for juveniles of other species (Moulton 1975).

The fall settlement period reported by Mathews (1988, 1990) for 1987 cohort juvenile quillback rockfish, or the complex of juvenile rockfishes, on BCAR, is in agreement with information from studies of the 1991 to 1994 cohorts of juvenile rockfishes on BCAR (see Chapter 2); however, the accuracy of the temporal densities and distributions reported for the 1987 cohort on BCAR are unknown, due to the possible inclusion of juvenile and sub-adult Puget Sound rockfish in the surveys. This also brings into question the accuracy of the temporal and spatial recruitment parameters reported for 1987 and 1988 cohort juvenile rockfishes on other Puget Sound habitats that may have included Puget Sound rockfish (see Mathews 1988, 1990).

### Recruitment of Juvenile *Sebastes caurinus*

The study of 1994 cohort juvenile copper rockfish recruitment in the San Juan Archipelago, confirmed the identification of this species and documented the temporal and spatial parameters of the first substrate associated recruitment (see Chapter 3). Studies from southern to northern areas in the range of copper rockfish, have found that the first substrate associated recruitment of the juveniles is in nearshore habitats, almost exclusively on macrophyte or seagrass substrates. In coastal California ecosystems, juvenile copper rockfish recruited to giant kelp (*Macrocystis pyrifera*) habitats (Anderson 1983, Hallacher and Roberts 1985, Carr 1991). In the Strait of Georgia, 102 km north of Puget Sound, juvenile copper rockfish recruited to bull kelp, eelgrass, and macrophyte habitats, and initially, in low densities, to sand habitat (Haldorson and Richards 1987). In the San Juan Archipelago, juvenile copper rockfish recruited to bull kelp, *Sargassum muticum*, and benthic macrophyte habitats, and to nearshore artificial structures.

The substrate associated recruitment of juvenile copper rockfish has not been documented directly in Puget Sound, because earlier studies usually grouped juvenile copper rockfish with quillback rockfish and brown rockfish juveniles, in a more easily identified complex of species. When species were separated in surveys of the 1994 cohort of juvenile rockfishes in north Puget Sound, there was virtually no recruitment of juvenile copper rockfish (see Chapter 2). Surveys of 1991 cohort juvenile rockfish recruitment in the San Juan Archipelago, provided some information on suspected juvenile copper rockfish in bull kelp and macrophyte habitats, which agreed with the recruitment parameters found for 1994 cohort juvenile copper rockfish in this ecosystem. The similarities in the recruitment pathways utilized by juvenile copper rockfish in coastal California ecosystems, the San Juan Archipelago, and the Strait of Georgia, indicate that information from these areas should apply to juvenile copper rockfish recruitment in similar nearshore habitats in Puget Sound.

The following model of spatial and temporal recruitment parameters and pathways, for the early phases of substrate associated recruitment of juvenile copper rockfish in the San Juan Archipelago and Puget Sound, is based primarily on information presented in Chapters 2 and 3 of this Dissertation research (Figure 5.2):

- I. Pre-settlement pelagic juveniles are in surface waters, possibly co-occurring with juvenile splitnose rockfish, with onshore movements to nearshore settlement habitats late in the pre-recruitment period; July and August (c-y d 1-62).

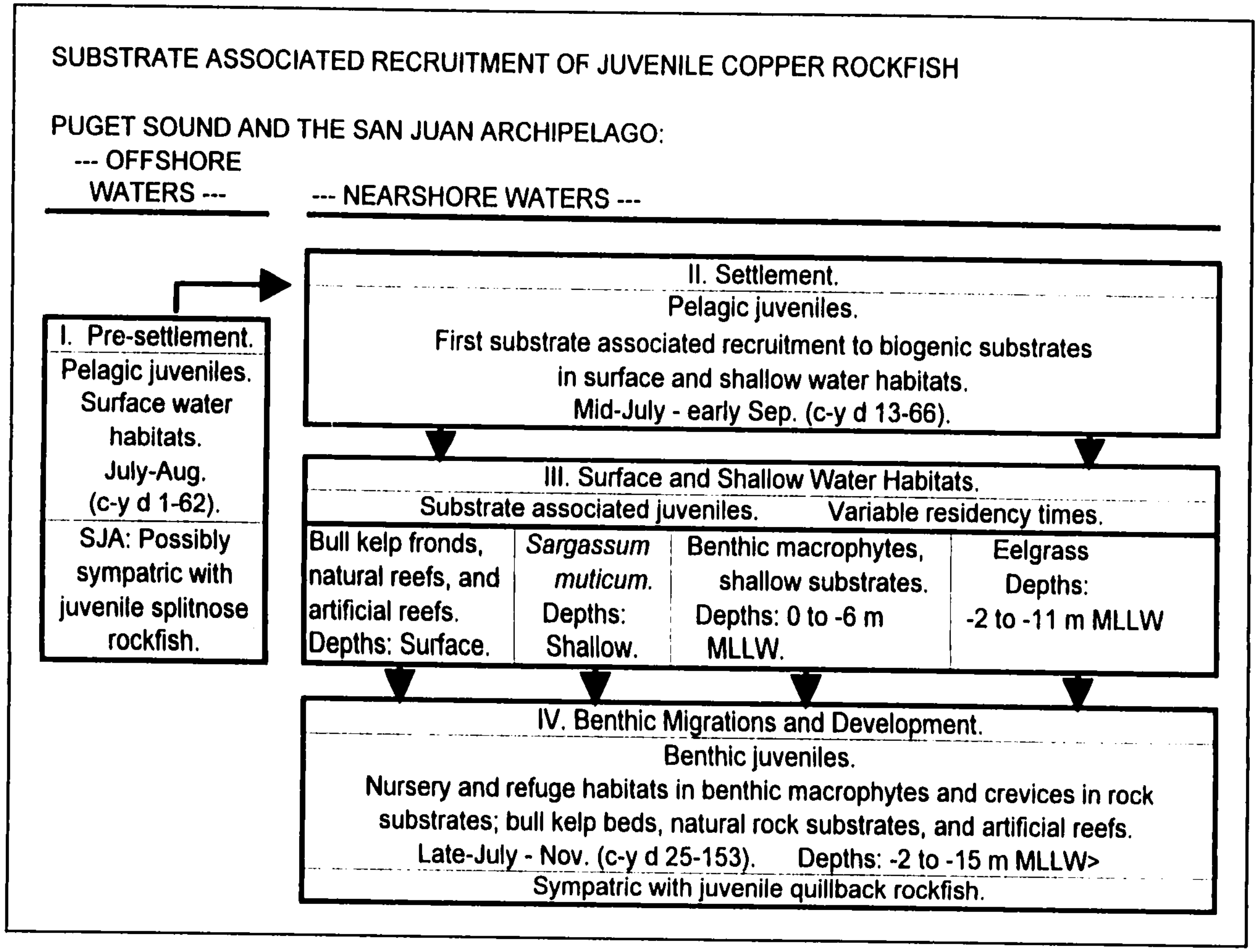

Figure 5.2. Model of spatial and temporal parameters and pathways for early substrate associated recruitment of juvenile copper rockfish in Puget Sound and the San Juan Archipelago.

Pelagic juvenile copper rockfish are moving onshore in the surface waters, and juvenile splitnose rockfish are recruiting to surface drift habitats, during this period (at least in the San Juan Archipelago), and the two species must co-occur in this habitat (see Chapter 4). One juvenile splitnose rockfish was found with juvenile copper rockfish in a surface nearshore habitat in the San Juan Archipelago.

- II. Pelagic juveniles recruit to various nearshore substrates in surface waters as the first substrate associated recruitment; recruitment substrates include bull kelp fronds, *S. muticum*, benthic macrophytes on shallow substrates, eelgrass, and, atypically, artificial structures; mid-July to early September (c-y d 13-66).

- III. Juveniles remain in the surface bull kelp frond habitat on artificial and natural reefs, and in eelgrass habitat, for undetermined periods before migrating deeper; juveniles in *S. muticum* and shallow macrophyte habitats appear to migrate quickly to intermediate depths (-5 to -6 m MLLW); juveniles have been found in eelgrass habitat at depths of -2 to -11 m (assumed MLLW).

- IV. Juveniles migrate from surface or shallow water habitats, to benthic macrophyte habitats; in bull kelp habitat on artificial and natural reefs, the benthic migration is usually associated with the bull kelp stipes as a physical recruitment pathway; migrations may occur from eelgrass habitat to artificial reef benthic macrophyte habitat; juveniles use benthic macrophytes, and crevices in the rock substrates, as nursery and refuge habitats; late July through November (c-y d 25-153); juveniles are sympatric with juvenile quillback rockfish.

### Recruitment Pathways of Sympatric Juveniles

Juvenile quillback rockfish appear to recruit to the same nearshore benthic macrophyte substrates later, and over a shorter period (i.e., c-y d 55-123), than juvenile copper rockfish (i.e., c-y d 25-153), in Puget Sound and the San Juan Archipelago. The species are sympatric, and, based on qualitative observations of the juxtapositions of juveniles of each species, there does not seem to be spatial partitioning of the habitat; however, micro-habitat preferences of juvenile quillback rockfish and juvenile copper rockfish have not been studied in local waters. Juvenile copper rockfish were noted to have significantly different micro-habitat preferences at different depths in coastal California giant kelp (*M. pyrifera*) habitat (Carr 1991). Sub-adult and adult quillback rockfish and copper rockfish are known to be sympatric in many habitats throughout their ranges (Murie 1991).

Juvenile quillback rockfish and copper rockfish appear to use the same recruitment pathways in migrations to offshore, deeper habitats in Puget Sound and the San Juan Archipelago. This is difficult to prove, however, because low recruitment of 1994 cohort juvenile copper rockfish in Puget Sound precluded concurrent and consecutive documentations of the habitat use patterns of both species. Determination of concurrent recruitment pathways is also confounded by earlier studies grouping the two species, due to identification difficulties. The common use of recruitment pathways by these juveniles may be dictated in many habitats by the lack of alternative substrates offering equivalent refuge potential; for example, benthic drift macrophytes moving across sand habitat.

The following model of spatial and temporal parameters of recruitment pathways for sympatric, substrate associated, juvenile quillback rockfish and copper rockfish, in the San Juan Archipelago and Puget Sound, is based primarily on information presented in Chapters 2 and 3 of this Dissertation research (Figure 5.3):

- V.A. Natural bull kelp and understory macrophyte habitat: Juveniles have strong habitat association with the seasonally deteriorating, benthic drift macrophyte habitat; drift macrophytes form a loose layer, up to 0.25 m thick, which creates the dominant benthic habitat complexity; juveniles use benthic drift macrophytes as nursery and refuge habitat; November through January (c-y d 124-215).

- V.B. Artificial reef recruitment substrate, and natural rock substrate, with benthic macrophyte habitat: Juveniles have strong habitat association with crevices in the substrate as nursery and refuge habitats; juveniles may have habitat association with the seasonally deteriorating, benthic macrophyte habitat if abundant; artificial reef recruitment substrate and natural rock substrate may have bull kelp and understory macrophyte habitat; November and December (c-y d 124-184).

- VI.A. Juveniles migrate offshore with the benthic drift macrophyte habitat as the habitat is transported out of the nearshore area by tidal currents; December through January (c-y d 154-215).

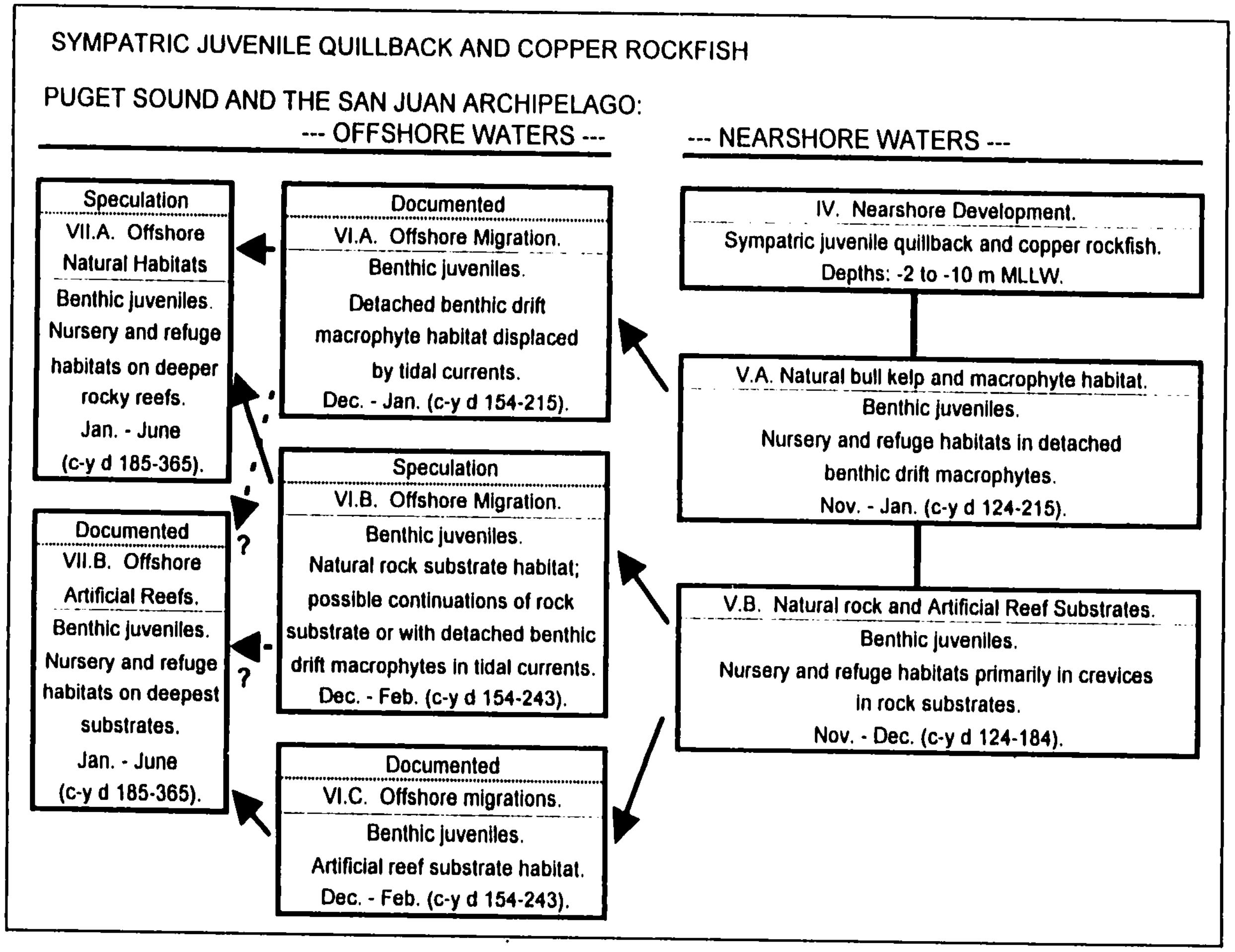

Figure 5.3. Model of spatial and temporal parameters and pathways for substrate associated post-recruitment migrations of sympatric juvenile quillback rockfish and copper rockfish in Puget Sound and the San Juan Archipelago.

- VI.B. Juveniles migrate to deeper depths with development, possibly following offshore continuations of the natural rock substrate; juveniles may migrate with offshore movements of benthic drift macrophyte habitat; December through February (c-y d 154-243).

- VI.C. Juveniles migrate to deeper depths with development, following offshore extensions of the artificial reef recruitment substrate; December through February (c-y d 154-243).

- VII.A. Juveniles speculated to become resident in offshore habitats, possibly on rocky reef areas at deeper depths; offshore habitats could be termination areas for transport of benthic drift macrophytes, or juveniles could extend migrations to more suitable habitats, including artificial reef recruitment substrates; some juveniles may be transported with the benthic drift macrophyte habitat to deeper areas of the artificial reef recruitment substrates; January through June (c-y d 185-365).

Juvenile migrations in offshore areas, to more suitable habitats, are supported by increases in densities of 1994 cohort juveniles on Boeing Creek and Gedney Island Artificial Reefs late in the cohort-year; on some habitats, juvenile densities increased to levels considerably higher than initial levels of recruitment. The juveniles found late in the cohort-year were of sizes appropriate for growth of September-October recruits, and did not represent an additional recruitment event. The increases in densities during late cohort-year surveys were partly artifacts of the juveniles emerging from the crevice habitats and becoming more visible during diurnal surveys. The artificial reef recruitment substrates provided optimal rocky reef habitat and would be expected to attract migrating juveniles.

- VII.B. Juveniles become resident on the deepest artificial reef recruitment substrates, at -10 to -18 m MLLW; some juveniles may migrate to the original artificial reef substrates; January through June (c-y d 185-365).

**Recruitment of Juvenile *Sebastes diploproa***

Surface drift habitats composed of detached macrophytes and seagrasses were present in all months of the year in the San Juan Archipelago and the Strait of Juan de Fuca. There was little temporal variability in the four primary components of this habitat, bull kelp, giant kelp, eelgrass, and rockweed (*Fucus distichus*), but there was spatial variability in the dominance of either bull kelp of giant kelp in the drift habitats depending upon the natural ranges of these species. The remaining one genus and seven species of macrophytes, and one genus of seagrass, found in the drift habitats, were present irregularly in moderate to trace amounts during the year, indicating possible temporal limitations (see Chapter 4).

Surveys of the 1992, 1993, and 1994 cohorts found that pelagic juvenile splitnose rockfish recruited to drift habitat substrates during June through August (i.e., c-y d 23 to 86[11] ), at sizes as small as 12 -15 mm TL, although maximum sizes found in the drift habitats in June indicate that pelagic juveniles were as large as 47 mm TL at recruitment. Substrate associated juveniles remained in

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[11] The cohort-year for substrate associated juvenile splitnose rockfish begins on June 1, 30 d prior to the July 1 datum used for inter-annual comparisons of substrate associated juvenile quillback rockfish and copper rockfish in this Dissertation research; cohort-year days for juvenile splitnose rockfish are given based on a June 1 to May 31 cohort-year.

drift habitats until November ( c-y d 160), and reached the maximum size in drift habitat of 51 mm TL, apparently, by August ( c-y d 86) of the cohort-year. Juvenile splitnose rockfish are known to migrate from drift habitat, to deep offshore adult habitats, at approximately this size in coastal California waters (Boehlert 1977).

Juvenile splitnose rockfish use the drift habitat substrates as nursery and refuge habitat (Buckley et al. 1995, Shaffer et al. 1995), and possibly as a vital or obligate recruitment pathway for high survival of the juveniles. Splitnose rockfish are sympatric with juvenile tiger rockfish (*S. nigrocinctus*) in the San Juan Archipelago, the Strait of Juan de Fuca, and Washington coastal waters. Tiger rockfish are present in drift habitat in low numbers, indicating that this is a habitat of opportunity for this species. Several other species of *Sebastes* have been found in drift habitat only in coastal waters (Washington Department of Fish and Wildlife, unpublished); juvenile quillback rockfish and juvenile copper rockfish have never been found in drift habitat.

The following model of spatial and temporal parameters and pathways of recruitment for substrate associated juvenile splitnose rockfish, in the San Juan Archipelago and the Strait of Juan de Fuca, is based primarily on information presented in Chapter 4 of this Dissertation research (Figure 5.4):

- I. Pre-settlement pelagic juveniles are in offshore surface waters, possibly for extended periods in pre-recruitment aggregations; prior to mid-June (<c-y d 15).

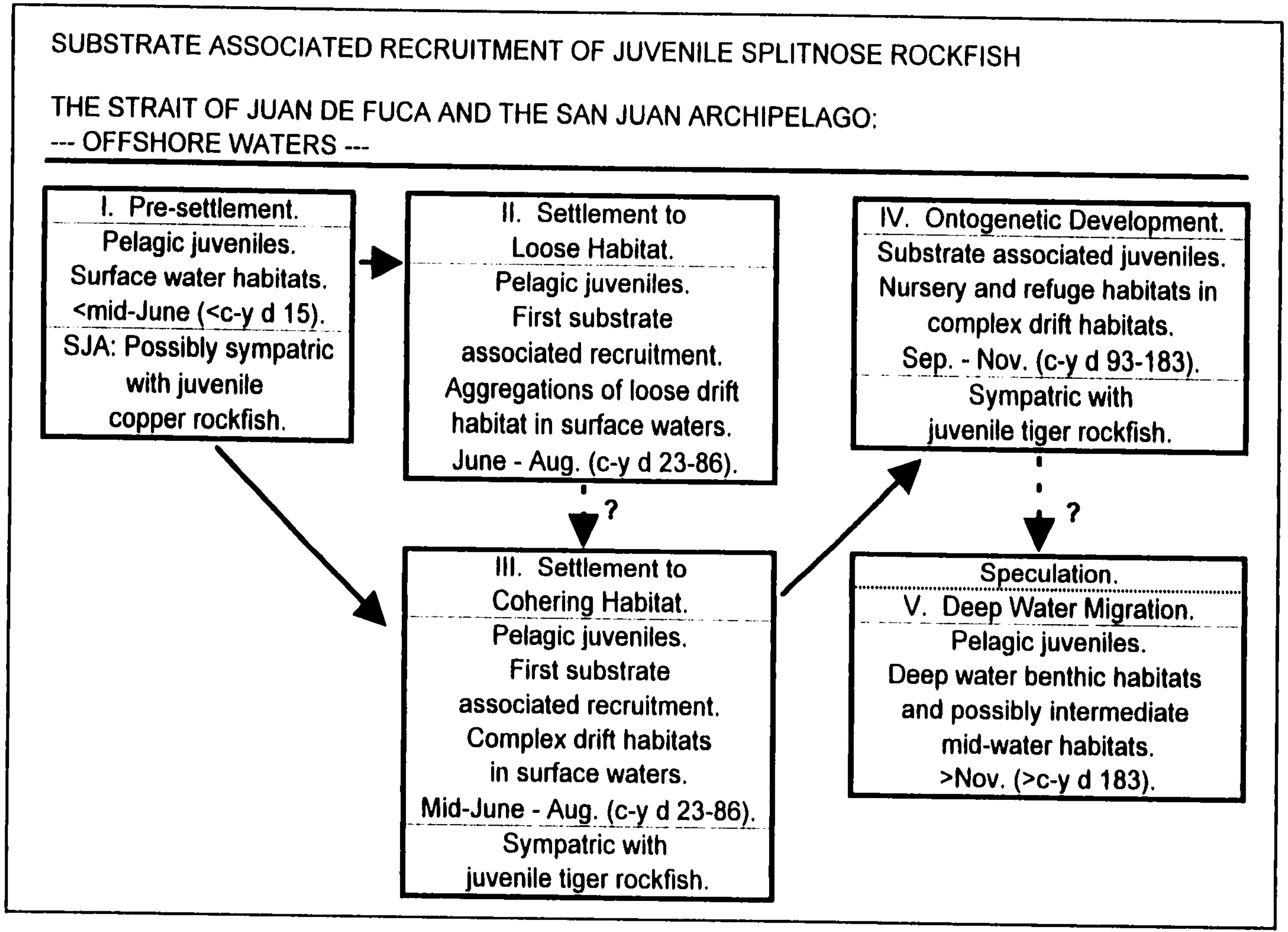

Figure 5.4. Model of spatial and temporal parameters and pathways for substrate associated recruitment of juvenile splitnose rockfish in the Strait of Juan de Fuca and the San Juan Archipelago.

This is based on the wide range of sizes of juveniles noted in the first substrate associated recruitment to drift habitat substrates. There are indications that pelagic stages of some *Sebastes* utilize surface waters as pre-recruitment habitat (Moser and Boehlert 1991). Juveniles are possibly sympatric with juvenile copper rockfish later in the pre-recruitment period.

- II. Pelagic juveniles recruit to loose aggregations of drift macrophytes and seagrasses in surface tidal current areas as the first substrate association; these aggregations may function as refuge habitats for temporal extensions of the surface water pre-recruitment period; possibly June through August (c-y d 23-86).

- III. Pelagic juveniles recruit to cohering aggregations of drift macrophytes and seagrasses forming surface mats of drift habitat as the first substrate association; pelagic juveniles may recruit from surface waters or loose aggregations of drift materials; mid-June through August (c-y d 23-86).

- IV. Juveniles use drift habitat as nursery habitat and refuge habitat; residency time appears related to a maximum size of approximately 50 mm TL in drift habitat; juveniles are sympatric with juvenile tiger rockfish; all juveniles vacate drift habitat by the end of November, apparently regardless of size; September through November (c-y d 93-183).

- V. Juveniles speculated to migrate to deep water benthic habitats at >50 mm TL, and by the end of November, apparently regardless of size; benthic habitats are apparently at adult depths; juveniles may be sympatric with older cohorts; juveniles vacating drift habitat over depths greater than adult habitat may have a recruitment pathway including variable residency times in deep mid-water habitats; >November (>c-y d 183).

This recruitment pathway is based on studies in California coastal ecosystems, where juvenile splitnose rockfish vacating drift habitat over depths greater than the benthic habitat of older cohorts, seemed to become resident in mid-water at the depth of the benthic habitat, and migrate onshore to the benthic habitat (Boehlert 1977). There is no evidence, however, that juvenile splitnose rockfish found in SJF and SJA survive to reach adult habitats.

## ENHANCEMENT OF JUVENILE *SEBASTES* RECRUITMENT HABITAT

The manipulations of the rock substrates at BCAR and GIAR, to add the ARH and IRH (i.e., adjacent recruitment habitat, and isolated recruitment habitat, respectively; see Chapter 2) at each location, were designed to determine if simulations of natural recruitment substrates in these artificial reef areas would function to enhance natural substrate associated recruitment of juvenile quillback rockfish and juvenile copper rockfish at these locations. The large sizes of the ARH and IRH substrates at BCAR and GIAR enabled assessments of recruitment and survival of these juvenile rockfishes at ecologically relevant scales. The scale of these experimental substrates was considered the most important experimental parameter in this Dissertation research. The importance of scale in conclusions reached in marine fish ecological studies has been demonstrated in several ecosystems (e.g., Brock et al. 1979, Doherty 1987, 1988, Jones 1990), concluding that ecological studies conducted at restricted spatial and temporal scales are usually relevant only at the levels of restrictions in the studies (Eberhardt and Thomas 1991, Ford 1995).

The natural scales of the ARH and IRH provided valuable information on ecosystem-level dynamics, but prevented replication of the experimental areas, or development of control areas, which is the usual analytical constraint of this study design (Doherty 1991, Ford 1995). Therefore, the hypothesis of enhanced substrate associated recruitment and survival of juvenile quillback rockfish and copper rockfish on the manipulated substrates could only be supported indirectly. Direct determinations of enhanced recruitment and survival would have required either (1) replication of BCAR and GIAR with and without substrate manipulations, or (2) long term comparative assessments of these parameters on BCAR and GIAR before and after the substrate manipulations. Neither of these approaches were possible because replication of the BCAR and GIAR complexes was not ecologically, physically, or economically feasible, and juvenile rockfish recruitment studies were not conducted prior to the substrate manipulations at BCAR and GIAR. However, limited observations of recruitment of the 1990 cohort of juvenile rockfishes on the original artificial reef at BCAR, prior to the 1991 substrate manipulations, noted that there were few juvenile rockfishes, and apparently few refuge habitats of sizes suitable for juvenile rockfishes, on the original artificial reef (see Chapter 2).

The ARH and IRH were designed to create abundant crevices in the rock substrate, and provide attachment substrates for benthic macrophytes, which would simulate the juvenile rockfish nursery and refuge habitats found on nearshore natural reefs in Puget Sound. The ARH and IRH substrates had greater densities of crevice habitats than near-by natural reefs that were recruitment habitats for juvenile rockfishes, but had similar benthic macrophyte communities. The temporal and spatial distributions of substrate associated juvenile rockfishes recruiting to the ARH and IRH at BCAR and GIAR, demonstrated that the juveniles were using the substrates and associated macrophytes as preferred nursery and refuge habitats. The 1991 cohort juvenile rockfishes that were tagged on BCAR IRH, remained in this habitat for 193 d, and did not emigrate to near-by natural or artificial reef habitats. The increased densities of 1994 cohort juveniles on BCAR IRH and GIAR ARH and IRH, at the end of the cohort-year, indicated emigration to these habitats from less suitable natural habitats. Juvenile rockfish preference for nearshore substrates with abundant crevice habitats, was also demonstrated when 1993 cohort juveniles in EKM remained on patch reef manipulations of the natural rock substrate that formed abundant crevice habitats, during the period of natural emigration from EKM.

This Dissertation research did not determine if the nearshore ecosystem in northern Puget Sound was recruitment habitat limited for juvenile rockfishes. It did appear from the results of this research that the most significant mortality of juvenile rockfishes occurred prior to substrate associated recruitment. However, it is likely that substantial amounts of the nearshore rock substrate and benthic macrophyte habitats used by juvenile rockfishes have been lost, or impacted, by the expanding urban shoreline development in this area over the last several decades (Washington Department of Fish and Wildlife, unpublished). This is especially likely along the highly urbanized northeastern shoreline of Puget Sound, where BCAR and GIAR were located. Surveys of the recruitment of 1991 and 1992 cohort juvenile rockfishes in natural nearshore habitats throughout central Puget Sound, found that virtually all of these juvenile rockfishes recruited along the eastern shoreline, possibly due to the effects of oceanographic parameters on the distributions of pelagic juveniles (Doty et al. 1995). If oceanographic factors influenced distributions of pelagic juvenile rockfishes in northern Puget Sound, and these factors directed pelagic juveniles toward the nearshore recruitment habitats most likely impacted by urbanization, then optimal recruitment habitat could be limited in this ecosystem. This would have favored recruitment to BCAR and GIAR.

The strongest evidence for enhanced substrate associated recruitment and survival of juvenile quillback rockfish and juvenile copper rockfish on the substrate manipulations at BCAR and GIAR, was provided by the recruitment of the 1991 through 1994 cohorts of juvenile rockfishes on the ARH and IRH at both locations (i.e., after the 1991 substrate manipulations). These four consecutive recruitment events in central Puget Sound occurred at relatively the same levels of intensity in natural habitats, and at BCAR and GIAR; the highest densities of juvenile rockfishes were from the 1991 cohort at all locations, followed consecutively by the 1992 and 1994 cohorts at all locations (comparative surveys were not made for the 1993 cohort; see Chapter 2). This demonstrated that the ARH and IRH were functioning as "natural" parts of the nearshore ecosystem in Puget Sound. Juvenile rockfishes remained in the ARH and IRH nursery and refuge habitats throughout the 1991 through 1994 cohort-years, and demonstrated average growth rates during the cohort-years that were similar between cohorts, and between areas, and similar to growth rates for juvenile rockfishes in other ecosystems. The survival rate estimated for the 1991 cohort juvenile quillback rockfish on BCAR, from tag recoveries, was the first estimated for a nearshore, demersal substrate associated juvenile *Sebastes*. There was no additional information for inter-specific comparisons within local

*Sebastes*, but the survival rate of these juveniles was higher than juveniles *Sebastes* in California coastal natural habitats.

Densities of substrate associated juvenile rockfishes on the ARH and IRH of BCAR and GIAR varied considerably between areas, and between cohort-years. Densities of 1991 and 1992 cohort juvenile rockfishes were greater on the IRH at BCAR, and greater for the 1991 cohort juveniles on the IRH at GIAR, indicating either higher levels of juvenile recruitment, or higher rates of juvenile survival, or both, on the IRH substrates (West et al. 1994, West et al. 1995). In contrast, at relatively lower levels of recruitment, and with virtually no recruitment of juvenile copper rockfish, there were no differences in the densities of 1994 cohort juvenile quillback rockfish on the IRH and ARH at both BCAR and GIAR. The efficacies of the ARH and IRH substrates are, at a minimum, affected by variability in levels of juvenile rockfish recruitment, variability in biogenic habitat parameters, and the increased ecological maturity of the substrates. The affects of these parameters on the substrate associated recruitment and survival of juvenile rockfishes on the ARH and IRH have not been determined. Consistent differences in the ARH and IRH designs, to enhance recruitment habitat for substrate associated juvenile *Sebastes*, are needed to determine the optimal artificial reef configuration.

The ARH and IRH rocky reef substrate manipulations at BCAR and GIAR enhanced the amounts of juvenile *Sebastes* recruitment habitats at these locations. The local affects of these recruitment substrates can be estimated, but any overall enhancement of juvenile rockfish recruitment in Puget Sound, resulting from these recruitment substrates, is difficult to determine. However, under variable levels of recruitment, these manipulations of the substrates at BCAR and GIAR functioned to enhance local natural substrate associated recruitment and survival of juvenile quillback rockfish and juvenile copper rockfish in northcentral Puget Sound. Further, it was clear that this enhanced recruitment of juvenile rockfishes was additive to the local areas, as substrate associated recruitment of the same species of juvenile rockfish continued in natural habitats near BCAR and GIAR after addition of the ARH and IRH recruitment substrates.

## LIST OF REFERENCES

Adams, P.B. and D.F. Howard. 1996. Natural mortality of blue rockfish, *Sebastes mystinus*, during their first year in nearshore benthic habitats. Fish. Bull. 94:156-162.

Ahlstrom, E.H. 1961. Distribution and relative abundance of rockfish (*Sebastodes* spp.) larvae off California and Baja California. Rapp. P.-V. Cons. Perm. Explor. Mer. 150:169-176.

Ainley, D.G., D.W. Anderson, and P.R. Kelly. 1981. Feeding ecology of marine cormorants in southwestern North America. Condor 83:120-131.

Ajaid, A.M., S. Mehl, K. Korsbrekke, A.V. Dolgov, V.A. Korzhov, V.L. Tretyak, and N.A. Yaragina. 1992. Trophic relationships and feeding-dependent growth in the north-east Arctic cod. Pages 45-58, In B. Bogstad and S. Tjelmeland, eds., Interrelationships between fish populations in the Barents Sea, Proceedings of the Fifth Pinro IMR Symposium, Murmansk , Russia 12-16 August 1991. Bergan, Norway, Institute of Marine Research 1992. (Abstract)

Aldenhoven, A.J. 1986. Local variation in mortality rates and life expectancy estimates of the coral reef fish Centropyge bicolor (Pisces: Pomacanthidae). Mar. Biol. 92:237-244.

Anderson, T.W. 1983. Identification and development of nearshore juvenile rockfishes (Genus *Sebastes*) in central California kelp forests. M.S. Thesis, California State University, Freseno.

Anderson, T.W. 1994. Role of macroalgal structure in the distribution and abundance of a temperate reef fish. Mar. Ecol. Prog. Ser. 113:279-290.

Anonymous. 1984. Synthesis of current measurements in Puget Sound, Washington - Volume 3: Circulation in Puget Sound: An interpretation based on historical records of currents. Dept. Comm. NOAA Tech. Memo. NOS OMS 5.

Anonymous. 1993. Diving Operations Manual. Wash. Dept. Fish. January 1993.

Archibald, C.P., D. Fournier, and B.M. Leaman. 1983. Reconstruction of stock history and development of rehabilitation strategies for Pacific Ocean perch in Queen Charlotte Sound, Canada. N. Amer. Jour. Fish. Mgt. 3:283-294.

Bairbridge, V. and G.A. Cooper. 1971. Populations of *Sebastes* larvae in the North Atlantic. Int. Comm. N.W. Atl. Fish. Res. Bull. 8:27-35.

Barsukov, V.V. 1981. A brief review of the subfamily Sebastinae. Jour. Icthyol. 21:1-26.

Behrents, K.C. 1987. The influence of shelter availability on recruitment and early survivorship of *Lythrypnus dalli* Gilbert. J. Exp. Mar. Biol. Ecol. 107:45-59.

Berestovskiy, E.G. 1989. Feeding in the skates, *Raja radiata* and *R. fyllae*. Jour.

Icthy. 29(8):88-96.

Bergman, P.K., F. Haw, H.L. Blankenship, and R.M. Buckley. 1992. Perspectives on design, use, and misuse of fish tags. Fish. 17(4):20-25.

Bergman, P.K., K.B. Jefferts, H.F. Fiscus, and R.L. Hager. 1968. A preliminary evaluation of an implanted coded wire fish tag. Wash. Dept. Fish. Res. Pap. 3:63-84.

Beukers, J.S., G.P. Jones, and R.M. Buckley. 1995. Use of implant microtags for studies on populations of small reef fish. Mar. Ecol. Prog. Ser. 125:61-66.

Blankenship, H.L. 1990. Effects of time and fish size on coded wire tag loss from chinook and coho salmon. Amer. Fish. Soc. Symp. 7:237-243.

Boehlert, G.W. 1977. Timing of the surface-to-benthic migration in juvenile rockfish, *Sebastes diploproa*, off southern California. Fish. Bull. 75(4):887-890.

Boehlert, G.W. 1981. The effects of photoperiod and temperature on laboratory growth of juvenile *Sebastes diploproa* and a comparison with growth in the field. U.S. Fish. Bull. 79:789-794.

Boehlert, G.W., M. Kusakari, M. Shimizu, and J. Yamada. 1986. Energetics during embryonic development in kurosoi, *Sebastes schlegeli* Hilgendorf. J. Exp. Mar. Biol. Ecol. 101:239-256.

Boehlert, G.W. and M.M. Yoklavich. 1984. Reproduction, embryonic energetics, and the maternal-fetal relationship in the viviparous genus *Sebastes* (Pisces: Scorpaenidae). Biol. Bull. 167:354-370.

Bohnsack, J.A. 1981. Effects of piscivorous predator removal on coral reef fish community structure. Gutshop '81, Wash. Sea Grant, pp. 258-267.

Bohnsack, J.A. and S.P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Tech. Rep. NMFS 41. 15 p.

Bohnsack, J.A. and D.L. Sutherland. 1985. Artificial reef research: a review with recommendations for future priorities. Bull. Mar. Sci. 37(1):11-39.

Bohnsack, J.A., D.L. Johnson, and R.F. Ambrose. 1991. Ecology of artificial reef habitats and fishes. Chapter 3, Pages 31-60, In W. Seaman, Jr. and L.M. Sprague, eds., Artificial habitats for marine and freshwater fisheries. Academic Press, Inc., San Diego, California.

Booth, D.J. and D.M. Brosnan. 1995. The role of recruitment dynamics in rocky shore and coral reef fish communities. Pages 309-385, In M. Begon and A.H. Fitter, eds., Advances in ecological research, Vol. 26. Academic Press, London.

Borland. 1992. Quattro Pro for Windows, version 1.0. Borland International, Inc., Scotts Valley, California.

Bradford, M.J. 1992. Precision of recruitment predictions from early life stages of marine fishes. Fish. Bull. 90(3):439-453.

Brock, R.E. 1982. A critique of the visual census method for assessing coral reef fish populations. Bull. Mar. Sci. 32:269-276.

Brock, R.E., C. Lewis, and R.C. Wass. 1979. Stability and structure of a fish community on a coral patch reef in Hawaii. Mar. Biol. 54:281-292.

Brock, V.E. 1954. A preliminary report on a method of estimating reef fish populations. J. Wildl. Mgmt. 18:297-308.

Brodeur, R.D. and W.G. Pearcy. 1984. Food habits and dietary overlap of some shelf rockfishes (Genus *Sebastes*) from the northeastern Pacific Ocean. Fish. Bull. 82(2):269-293.

Buckley, R.M. 1982. Marine habitat enhancement and urban recreational fishing in Washington. Mar. Fish. Rev. 44:28-37.

Buckley, R.M. 1985. Habitat enhancement and urban recreational fishing. Chapter 14, Pages 365-382, In F.M. D'Itri, ed., Artificial Reefs - Marine and Freshwater Applications. Lewis Publishers, Inc., Michigan.

Buckley, R.M. 1989. Habitat alterations as a basis for enhancing marine fisheries. CalCOFI Rep. 30:40-45.

Buckley, R.M., M.C. Gómez-Buckley. 1992. Internal micro-tag identification systems for teleosts, holothurians, and decapods. Proc. 7th Inter. Coral Reef Symp. 2:1029. (Abstract)

Buckley, R.M., M.C. Gómez-Buckley, D.C. Doty, J.E. West, and B.S. Miller. 1995. Recruitment ecology of juvenile rockfishes (*Sebastes* spp) in drift habitat in Juan de Fuca Strait and the San Juan Archipelago, Washington. Pages 203-223, In Vol. 1: Proceedings Puget Sound Research '95, Bellevue, Washington 1995, Puget Sound Water Quality Authority, Olympia, Washington.

Buckley, R.M. and H.L. Blankenship. 1990. Internal extrinsic identification systems: overview of implanted wire tags, otolith marks, and parasites. Amer. Fish. Soc. Symp. 7:173-182.

Buckley, R.M. and G. J. Hueckel. 1985. Biological processes and ecological development on an artificial reef in Puget Sound, Washington. Bull. Mar. Sci. 37(1):50-69.

Buckley, R.M. and G. J. Hueckel. 1989. Analysis of visual transects for fish assessment on artificial reefs. Bull. Mar. Sci. 44(2):893-898.

Buckley, R., G. Hueckel, B. Benson, S. Quinell, and M. Canfield. 1984. Enhancement research on lingcod (*Ophiodon elongatus*) in Puget Sound. Wash. Dept. Fish. Prog. Rep. No. 216. 93 p.

Buckley, R.M., J.E. West and D.C. Doty. 1994 Internal micro-tag systems for marking juvenile reef fishes. Bull. Mar. Sci. 52(2 and 3):848-857.

Caley, M.J. 1995. Reef-fish community structure and dynamics: an interaction between local and larger scale processes? Mar. Ecol. Prog. Ser. 129:19-29.

Carlson, H.R. and R.R. Straty. 1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes* spp., in rocky coastal areas of southeastern Alaska. Mar. Fish. Rev. 43(7):13-19.

Carr, M.H. 1983. Spatial and temporal patterns of recruitment of young-of-the-year rockfishes (genus *Sebastes*) into a central California kelp forest. M.S. Thesis, San Francisco State University, San Francisco.

Carr, M.H. 1989. Effects of macroalgal assemblages on the recruitment of temperate zone reef fishes. J. Exp. Mar. Biol. Ecol. 126:59-76.

Carr, M.H. 1991. Habitat selection and recruitment of an assemblage of temperate zone reef fishes. J. Exp. Mar. Biol. Ecol. 146:113-137.

Carr, M.H. 1994a. Effects of macroalgal dynamics on recruitment of a temperate reef fish. Ecol. 75(5):1320-1333.

Carr, M.H. 1994b. Predicting recruitment of temperate reef fishes in response to changes in macrophyte density caused by disturbance. Pages 255-269, In D.J. Stouder, K.L. Fresh, and R.J. Feller, eds., Theory and application in fish feeding ecology. B.W. Baruch Lib. Mar. Sci. No. 18, University of South Carolina Press, South Carolina U.S.A.

Casa, J.M., F. Saborido and J. Paz. 1991. Predacion del bacalao (*Gadus morula*) sobre gallineta nordica (*Sebastes* spp.) en Flemish Cap. Bol. Inst. Esp. Oceanogr. 7(1):45-58. (Abstract)

Casas, J.M. and J. Paz. 1994. Diet of Flemish Cap cod with particular reference to predation on redfish: 1988-1993. NAFO Sci. Cncl. Res. Doc. 1994. No. 94-24, 21 p. (Abstract)

Casas, J.M. and J. Paz. 1996. Recent changes in the feeding of cod (*Gadus morhua*) off the Flemish Cap, Newfoundland 1989-1993. ICES Jour. Mar. Sci. 53:750-756.

Chen, L. 1971. Systematics, variation, distribution, and biology of the subgenus *Sebastomus* (Pisces, Scorpaenidae, *Sebastes*). Bull. Scripps Inst. Oceanogr. 18:1-115.

Chen, L. 1986. Meristic variation in *Sebastes* (Scorpaenidae), with an analysis of character association and bilateral pattern and their significance in species separation. U.S. Dept. Commerce, NOAA Tech. Rept. NMFS 45, 25p.

Choat, J.H. and A.M. Ayling. 1987. The relationship between habitat structure and fish faunas on New Zealand reefs. J. Exp. Mar. Biol. Ecol. 110:257-284.

Cochran, W.G. 1977. Sampling techniques. Third Edition. John Wiley & Sons, New York.

Cokelet, E.D., R.J. Stewart, and C.C. Ebbesmeyer. 1991. Concentrations and ages of conservative pollutants in Puget Sound. Pages 99-108, In Vol. 1: Proceedings Puget Sound Research '91, Seattle, Washington 1991, Puget Sound Water Quality Authority, Olympia, Washington.

Collias, E.E. and C.A. Barnes. 1966. Physical and chemical data for Puget Sound and approaches, Jan. 1960 - Dec. 1961. Univ. Wash., Dept. Oceanog., Tech. Rep. 114, 286p.

Connell, S.D. and G.P. Jones. 1991. The influence of habitat complexity on post recruitment processes in a temperate reef fish population. J. Exp. Mar. Biol. Ecol. 151:271-294.

Connelley, R.M. 1994. Removal of seagrass canopy: effects on small fish and their prey. J. Exp. Mar. Biol. Ecol. 184:99-110.

Dahl, A.L. 1973. Surface area in ecological analysis: quantification of benthic coral-reef algae. Mar. Biol. 23:239-249.

Danner, E.M., T.C. Wilson, and R.E. Schlotterbeck. 1994. Comparisons of rockfish recruitment on nearshore artificial and natural reefs off the coast of Central California. Bull. Mar. Sci. 55(2 and 3):333-343.

Dawe, E.G. 1992. Predation by short-finned squid on Atlantic cod and other fish at Newfoundland, Canada. Cncl. Meet. Int. Cncl. Exp. Sea (ICES), 24 Sep. - 2 Oct. 1992. (Abstract)

DeLacy, A.C., C.R. Hitz, and R.L. Dryfoos. 1964. Maturation, gestation, and birth of rockfish (*Sebastodes*) from Washington and adjacent waters. Wash. Dept. Fish., Fish. Res. Paper 2(3):51-67.

DeMartini, E.E. and D. Roberts. 1982. An empirical test of biases in the rapid visual technique for species-time censuses of reef fish assemblages. Mar. Biol. 70:129-134.

Doherty, P.J. 1987. The replenishment of populations of coral reef fishes, recruitment surveys, and the problems of variability manifest on multiple scales. Bull. Mar. Sci. 41(2):411-422.

Doherty, P.J. 1988. Large-scale variability in the recruitment of a coral reef fish. Proc. 6th Int. Coral Reef Symp. 2:667-672.

Doherty, P.J. 1991. Spatial and temporal patterns in recruitment. Pages 261-293, In P.F. Sale, ed. The ecology of coral reef fishes. Academic Press, San Diego, California U.S.A.

Doherty, P.J. and D. McB. Williams. 1988a. The replenishment of coral reef fish populations. Ocean. Mar. Biol. Ann. Rev. 26:487-551.

Doherty, P.J. and D. McB. Williams. 1988b. Are local populations of coral reef fishes equilibrial assemblages? The empirical database. Proc. 6th Int. Coral Reef Symp. 1:131-139.

Dolgaya, O.Y. and V.L. Tretyak. 1992. Significance of the north-east Arctic cod for year-class strength of redfish in the Barnets Sea. Pages 39-44 In B. Bogstad and S. Tjelmeland, eds., Interrelations between fish populations in the Barnets Sea. Proceedings 5th PINRO IMR Symp., Murmansk, Russia, 12-16 Aug. 1991. Inst. Mar. Res. Bergen, Norway 1992. (Abstract)

Donnelly, R., B. Miller, R. Lauth, and J. Shriner. 1984. Fish ecology. In Renton sewage treatment plant project: Seahurst baseline study. Vol. VI. Sec. 7, Final Report. FRI-UW-8413.

Dooley, J.K. 1972. Fishes associated with the pelagic *Sargassum* complex, with a discussion of the *Sargassum* community. Cont. Mar. Sci. 16:1-32.

Doty, D.C., R.M. Buckley, and J.E. West. 1995. Identification and protection of nursery habitats for juvenile rockfish in Puget Sound, Washington. Pages 181-190, In Vol. 1. Proceedings Puget Sound research '95, Bellevue, Washington 1995, Puget Sound Water Quality Authority, Olympia, Washington.

Duggins, D.O. and J.E. Eckman. 1994. The role of kelp detritus in the growth of benthic suspension feeders in an understory kelp forest. J. Exp. Mar. Biol. Ecol. 176:53-68.

Dygert, P.H. and D.R. Gunderson. 1991. Energy utilization by embryos during gestation in viviparous copper rockfish, *Sebastes caurinus*. Env. Biol. Fish. 30:165-171.

Ebeling, A.W. and M.A. Hixon. 1991. Tropical and temperate reef fishes: comparison of community structures. Pages 509-563, In P.F. Sale, ed. The ecology of coral reef fishes. Academic Press, San Diego, California U.S.A.

Eberhardt, L.L. and J.M. Thomas. 1991. Designing environmental field studies. Ecol. Monog. 61(1):53-73.

Eckert, G.J. 1987. Estimates of adult and juvenile mortality for labrid fishes at One Tree Reef, Great Barrier Reef. Mar. Biol. 95:167-171.

Fedoryako, B.I. 1989. A comparative characteristic of oceanic fish assemblages associated with floating debris. Jour. Icthy. 29(3):128-137.

Ford, E.D. 1995. Analysis and synthesis in ecological research: an introduction. Unpub. Manus., Cntr. Quant. Sci., Univ. Wash., Seattle, WA.

Forrester, G.E. 1990. Factors influencing the juvenile demography of a coral reef fish. Ecol. 71(5):1666-1681.

Forrester, G.E. 1995. Strong density-dependent survival and recruitment regulate the abundance of a coral reef fish. Oecol. 103:275-282.

Fortier, L. and A. Villeneuve. 1996. Cannibalism and predation on fish larvae by larvae of Atlantic mackerel, *Scomber scombrus*: trophodynamics and potential impact on recruitment. Fish. Bull. 94:268-281.

Franks, P.S. 1992. Sink or swim: accumulation of biomass at fronts. Mar. Ecol. Prog. Ser. 82:1-12.

Frederick, J.L. In press. Evaluation of fluorescent elastomer injection as a method for marking small fish. Bull. Mar. Sci.

Gascon, D. and R.A. Miller. 1981. Colonization by nearshore fish on small artificial reefs in Barkley Sound, British Columbia. Can. Jour. Zool. 9:1635-1646.

Gaines, S.D. and J. Roughgarden. 1987. Fish in offshore kelp forests affect recruitment to intertidal barnacle populations. Sci. 235:479-481.

Gilliam, J.F. and D.F. Fraser. 1987. Habitat selection under predation hazard: test of a model with foraging minnows. Ecol. 68(6):1856-1882.

Gorelova, T.A. and B.I. Fedoryako. 1986. Topic and trophic relationships of fishes associated with drifting *Sargassum* algae. Jour. Icthy. 26(2):63-72.

Gowan, R.E. 1983. Population dynamics and exploitation rates of rockfish (*Sebastes* spp.) in central Puget Sound, Washington. Ph.D. Diss. Univ. Wash., Seattle, Wash.

Haldorson, L. 1987. Introduction. Pages 1-4, In Proceedings International Rockfish Symposium, October 1986, Anchorage, Alaska, Univ. Alaska, Alaska Sea Grant Rep. 87-2.

Haldorson, L. and M. Love. 1991. Maturity and fecundity in the rockfishes, *Sebastes* spp., a review. Mar. Fish. Rev. 53(2):25-31.

Haldorson, L.J. and L.J. Richards. 1987. Post-larval copper rockfish in the Strait of Georgia: habitat use, feeding, and growth in the first year. Pages 129-141, In Proceedings International Rockfish Symposium, October 1986, Anchorage, Alaska, Univ. Alaska, Alaska Sea Grant Rep. 87-2.

Hallacher, L.E. and D.A. Roberts. 1985. Differential utilization of space and food by the inshore rockfishes (Scorpaenidae: *Sebastes*) of Carmel Bay, California. Env. Biol. Fish. 12:91-110.

Harrold, C. and S. Lisin. 1989. Radio-tracking rafts of giant kelp: local production and regional transport. J. Exp. Mar. Biol. Ecol. 130:237-251.

Hart, J.L. 1980. Pacific fishes of Canada. Fish. Res. Bd. Can. Bull. 180.

Haw, F., P.K. Bergman, R.D. Fralick, R.M. Buckley, and H.L. Blankenship. 1990. A visible implanted fish tag. Amer. Fish. Soc. Symp. 7:311-315.

Haw, F. and R.M. Buckley. 1971. Saltwater fishing in Washington. Stan Jones Pub. Co., Seattle.

Hitz, C.R. 1961. Occurrence of two species of juvenile rockfish in Queen Charlotte Sound. Jour. Fish. Res. Bd. Canada 18(2):279-281.

Hixon, M.A. 1991. Predation as a process structuring coral reef fish communities. Pages 475-508 In P.F. Sale ed., The ecology of coral reef fishes. Academic Press, New York, New York, U.S.A.

Hixon, M.A. and J.P. Beets. 1989. Shelter characteristics and Caribbean fish assemblages: experiments with artificial reefs. Bull. Mar. Sci. 44:666-680. Hixon, M.A. and J.P. Beets. 1993. Predation, prey refuges, and the structure of coral-reef fish assemblages. Ecol. Monog. 63:77-101.

Hobson, E.S. (ed.). 1989. Progress in rockfish recruitment studies. NOAA/NMFS SW Fish. Cntr. Admin. Rep. T-89-01.

Hobson, E.S. and D.F. Howard. 1989. Mass strandings of juvenile shortbelly rockfish and Pacific hake along the coast of northern California. Calif. Fish Game 75(3):169-183.

Hobson, E.S. and J.R. Chess. 1976. Trophic interactions among zooplankters near shore at Santa Catalina Island, California. U.S. Fish. Bull. 74:567-598.

Hobson, E., P. Adams, J. Chess, D. Howard, and W. Samiere. 1986. Temporal and spatial variations in the numbers of first-year juvenile rockfishes off northern California. NOAA/NMFS SW Fish. Cntr. Admin. Rep. T-86-02.

Hodgson, L.M. and J.R. Waaland. 1979. Seasonal variation in the subtidal macroalgae of Fox Island, Puget Sound, Washington. Syesis 12:107-112.

Holbrook, S.J., M.H. Carr, R.J. Schmitt, and J.A. Coyer. 1990a. Effect of giant kelp on local abundance of reef fishes: the importance of ontogenetic resource requirements. Bull. Mar. Sci. 47(1):104-114.

Holbrook, S.J., R.S. Schmitt and R.F. Ambrose. 1990b. Biogenic habitat structure and characteristics of temperate reef fish assemblages. Aust. J. Ecol. 15:489-503.

Hueckel, G.J. and R.M. Buckley. 1987. The influence of prey communities on fish species assemblages on artificial reefs in Puget Sound, Washington. Envir. Biol. Fish. 19(3):195-214.

Hueckel, G.J. and R.M. Buckley. 1989. Predicting fish species on artificial reefs using indicator biota from natural reefs. Bull. Mar. Sci. 44(2):873-880.

Hueckel, G.J. and R.L. Stayton. 1982. Fish foraging on an artificial reef in Puget Sound, Washington. Mar. Fish. Rev. 44:38-44.

Hunte, W. and I.M. Côté. 1989. Recruitment in the redlip blenny *Ophioblennius atlanticus:* is space limiting? Coral Reefs 8:45-50.

Hunter, J.R., D.C. Aasted, and C.T. Mitchell. 1966. Design and use of a miniature purse seine. Prog. Fish Cult. 3:175-179.

Isaksson, A. and P.K. Bergman. 1978. A evaluation of two tagging methods and survival rates of different age and treatment groups of hatchery-reared Atlantic salmon smolts. Jour. Agri. Res. Iceland 10(1):74-99.

Jennings, S. and N.V.C. Polunin. 1995. Biased underwater visual census biomass estimates for target-species in tropical reef fisheries. Jour. Fish Biol. 47:733-736.

Jones, G.P. 1984. Population ecology of a temperate reef fish *Pseudolabrus celidotus* Bloch and Schneider (Pisces: Labridae). I. Factors influencing recruitment. J. Exp. Mar. Biol. Ecol. 75:257-276.

Jones, G.P. 1987a. Competitive interactions among adults and juveniles in a coral reef fish. Ecol. 68(5):1534-1547.

Jones, G.P. 1987b. Some interactions between residents and recruits in two coral reef fishes. J. Exp. Mar. Biol. Ecol. 114:169-182.

Jones, G.P. 1988a. Ecology of rocky reef fish of north-eastern New Zealand: a review. N.Z. Jour. Mar. Fresh. Res. 22:445-462.

Jones, G.P. 1988b. Experimental evaluation of the effects of habitat structure and competitive interactions on the juveniles of two coral reef fishes. J. Exp. Mar. Biol. Ecol. 123:115-126.

Jones, G.P. 1990. The importance of recruitment to the dynamics of a coral reef fish population. Ecol. 71(5):1691-1698.

Jones, G.P. 1991. Post recruitment processes in the ecology of coral reef fish populations: a multifactorial perspective. Pages 294-328, In P.F. Sale, ed. The ecology of coral reef fishes. Academic Press, San Diego, California U.S.A.

Jones, R.S. and M.J. Thompson. 1978. Comparison of Florida reef fish assemblages using a rapid visual technique. Bull Mar. Sci. 28:159-172.

Kendall, A.W, Jr. 1989. Additions to knowledge of *Sebastes* larvae through recent rearings. NW Alaska Fish. Cntr. Proc. Rep. 89-21.

Kendall, A.W., Jr. 1991. Systematics and identification of larvae and juveniles of the genus *Sebastes*. Env. Biol. Fish. 30:173-190.

Kendall, A.W., Jr. and W.H. Lenarz. 1987. Status of early life history studies of northeast Pacific rockfishes. Pages 99-128 In Proceedings of the International Rockfish Symposium, Anchorage Alaska USA, October 20-22, 1986. Alaska Sea Grant Report No. 87-2.

Kingsford, M.J. 1992. Drift algae and small fish in coastal waters of northeastern New Zealand. Mar. Ecol. Prog. Ser. 80:41-55.

Kingsford, M.J. and J.H. Choat. 1985. The fauna associated with drift algae captured with a plankton-mesh purse seine net. Limnol. Oceanogr. 30:618-630.

Kingsford, M.J. and J.H. Choat. 1986. Influence of surface slicks on the distribution and onshore movements of small fish. Mar. Biol. 91:161-171.

Klar, G.T. and N.C. Parker. 1986. Marking fingerling striped bass and blue tilapia with coded wire tags and microtaggants. N. Amer. J. Fish. Mgt. 6:439-444.

Kulczycki, G.R., R.W. Virnstein, and W.G. Nelson. 1981. The relationship between fish abundance and algal biomass in a seagrass-drift algae community. Estuar. Coast. Shelf Sci. 12:341-347.

Kusakari, M. 1991. Mariculture of kurosoi, *Sebastes schlegeli*. Env. Biol. Fish. 30:245-251.

Laroche, W.A. and S.L. Richardson. 1980. Development and occurrence of larvae and juveniles of the rockfishes *Sebastes flavidus* and *Sebastes melanops* (Scorpaenidae) off Oregon. Fish. Bull. 77(4):901-924.

Larson, R.J. (ed.). 1987. Progress in rockfish recruitment studies. NOAA/NMFS SW Fish. Cntr. Admin. Rep. T-87-01.

Larson, R.J. 1980. Competition, habitat selection, and the bathymetric segregation of two rockfish species. Ecol. Monogr. 50:221-239.

Larson, R.J. 1991. Seasonal cycles of reserves in relation to reproduction in *Sebastes*. Envir. Biol. Fish. 30:57-70.

Larson, R.J., W.H. Lenarz, and S. Ralston. 1994. The distribution of pelagic juvenile rockfish of the genus *Sebastes* in the upwelling region off central California. CalCOFI Rep. 35:175-221.

Lebreton, J.D., K.P. Burnham, J. Colbert, and D.R. Anderson. 1992. Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecol. Monogr. 62:67-118.

Leet, M.H. and C.A. Reilly. 1988. Annotated bibliography of the genus *Sebastes* (Family Scorpaenidae). Pac. Mar. Fish. Comm., Portland, Oregon.

Lenarz, W. and S. Moreland. 1985. Progress report on rockfish recruitment studies at the Tiburon laboratory. NOAA/NMFS SW Fish. Cntr. Admin. Rep. T-85-02.

Levin, P.S. 1991. Effects of microhabitat on recruitment variation in a Gulf of Maine reef fish. Mar. Ecol. Prog. Ser. 75:183-189.

Levin, P.S. 1994. Small-scale recruitment variation in a temperate fish: the roles of macrophytes and food supply. Env. Biol. Fish. 40:271-281.

Lively, C.M. 1988. A graphical model for shell-species selection by hermit crabs. Ecol. 69(4):1233-1238.

Loew, E.R. and W.N. McFarland. 1990. The underwater visual environment. Pages 1-43, In N.R. Douglas and M. Djamgoz, eds., The Visual System of Fish. Chapman & Hall, London.

Loi, T. 1981. Environmental stresses and intertidal assemblages on hard substrates in the Port of Long Beach, California, USA. Mar. Biol. 63:197-211.

Love, M.S., P. Morris, M. McCrae, and R. Collins. 1990. Life history aspects of 19 rockfish species (Scorpaenidae: *Sebastes*) from the southern California Bight. NOAA Tech. Rep. NMFS 87, 38p.

Love, M.S., M.H. Carr, and L.J. Haldorson. 1991. The ecology of substrate-associated juveniles of the genus *Sebastes*. Envir. Biol. Fish. 30:225-243.

Love, M.S. and W.V. Westphal. 1981. Growth, reproduction, and food habits of olive rockfish, *Sebastes serranoides*, off central California. Fish. Bull. 79(3):533-545.

Luckhurst, B.E. and K. Luckhurst. 1978. Analysis of the influence of substrate variables on coral reef fish communities. Mar. Biol. 49:317-323.

Magnusson, J.V. and O.K. Palsson. 1989. The feeding habits of cod and redfish in East Greenland waters, with special emphasis on predation on juvenile redfish. Page 465 In J.H.S. Blaxter, J.C. Gamble, and H. von

Westernhagen, eds. The early life history of fish. The 3rd Int. Council. Exp. Sea Symp.,Bergen, Norway, 3-5 Oct. 1988. (Summary)

Masuda, H., K.Amaoka, C. Araga, T. Uyeno, and T. Yoshino. 1984. Fishes of the Japanese Archipelago. Tokai Univ. Press, Tokyo, 450p.

Mathews, K.R. 1988. Habitat use and movement patterns of copper, quillback, and brown rockfishes in Puget Sound, Washington. Dissertation. University of Washington, Seattle, Washington U.S.A.

Mathews, K. 1990. A comparative study of habitat use by young-of-the-year, sub-adult, and adult rockfishes on four habitat types in central Puget Sound. Fish. Bull. 88(2):223-239.

Matarese, A.C., A.W. Kendall, Jr., D.M. Blood, and B.M. Vinter. 1989. Laboratory guide to early life history stages of northeast Pacific fishes. NOAA Tech. Rep. NMFS 80.

McCormick, M.I. 1994. Comparison of field methods for measuring surface topography and their associations with a tropical reef fish assemblage. Mar. Ecol. Prog. Ser. 112:87-96.

McCormick, M.I. and J.H. Choat. 1987. Estimating total abundance of a large temperate-reef fish using visual strip-transects. Mar. Biol. 96:469-478.

McFarland, W.N. 1986. Light in the sea - Correlations with behaviors of fishes and invertebrates. Am. Zool. 26:389-401.

McFarland, W.N. 1991. The visual world of coral reef fishes. Pages 16-38, In P.F. Sale, ed. The Ecology of Fishes on Coral Reefs. Academic Press, Inc., San Diego.

McGary, N. 1977. Tide prints: surface tidal currents in Puget Sound. Wash. Sea Grant Pub. WSG 77-1.

Meekan, M.G. 1988. Settlement and mortality patterns of juvenile reef fishes at Lizards Island northern Great Barrier Reef. Proc. 6th Int. Coral Reef Symp. 2:779-784.

Meese, R.J. and P.A. Tomich. 1992. Dots on the rocks: a comparison of percent cover estimation methods. J. Exp. Mar. Biol. Ecol. 165:59-73.

Microsoft. 1989. Microsoft Paintbsush, version 4.0. Microsoft Corporation, Redmond, Washington.

Microsoft. 1994. Microsoft Excel, version 5.0. Microsoft Corporation, Redmond, Washington.

Milicich, M.J. 1994. Dynamic coupling of reef fish replenishment and oceanographic processes. Mar. Ecol. Prog. Ser. 110:135-144.

Miller, B.S. and S.F. Borton. 1980. Geographical distribution of Puget Sound fishes: maps and data source sheets. Vol. 2. Family Percichthyidae to

Family Hexagrammidae. Fish. Res. Inst., Univ. of Washington, Seattle.

Miller, B.S., C.A. Simenstad, L.L. Moulton, K.L. Fresh, F.C. Funk, W.A. Karp, and S.F. Borton. 1977. Puget Sound baseline program nearshore fish survey. Fish. Res. Inst. Univ. Wash. FRI-UW-7710.

Mitchell, C.T. and J.R. Hunter. 1970. Fishes associated with drifting kelp, *Macrocystis pyrifera*, off the coast of southern California and northern Baja California. Calif. Fish and Game 56(4):288-297.

Moreno, C.A. and H.F. Jara. 1984. Ecological studies on fish fauna associated with *Macrocystis pyrifera* belts in the south of Fueguian Islands, Chile. Mar. Ecol. Prog. Ser. 15:99-107.

Moreland, S.L. and C.A. Reilly. 1991. Key to the juvenile rockfishes of central California. NOAA NMFS SFSC.

Moser, H.G., E.H. Ahlstrom, and E.M. Sandknop. 1977. Guide to the identification of scorpionfish larvae (family Scorpaenidae) in the eastern Pacific with comparative notes on species of *Sebastes* and *Helicolenus* from other oceans. NOAA Tech. Rept., NMFS Cir. 402.

Moser, H.G. and G.W. Boehlert. 1991. Ecology of pelagic larvae and juveniles of the genus *Sebastes*. Envir. Biol. Fish. 30:203-224.

Moulton, L.L. 1975. Life history observations on the Puget Sound rockfish, *Sebastes emphaeus* (Starks, 1911). J. Fish. Res. Board Can. 32(8):1439-1442.

Moulton, L.L. 1977. An ecological analysis of fishes inhabiting the rocky nearshore regions of northern Puget Sound, Washington. Dissertation. Univ. Wash. Seattle, Wash.

Murie, D.J. 1991. Comparative ecology and interspecific competition between the sympatric congeners *Sebastes caurinus* (copper rockfish) and *S. maliger* (quillback rockfish). Dissertation. Univ. Victoria, Victoria, British Columbia.

Murie, D.J. 1995. Comparative feeding ecology of two sympatric rockfish congeners, *Sebastes caurinus* (copper rockfish) and *S. maliger* (quillback rockfish). Mar. Biol. 124:341-353.

Murie, D.J., D.C. Parkyn, B.G. Clapp, and G.G. Krause. 1994. Observations on the distribution and activities of rockfish, *Sebastes* spp., in Saanich Inlet, British Columbia, from the Pisces IV submersible. Fish. Bull. 92:313-323.

National Ocean Service. 1984. Synthesis of current measurements in Puget Sound, Washington - Volume 3. Circulation in Puget Sound: an interpretation based on historical records of currents. NOAA Tech. Memo. NOS OMS 5, 69p.

Neilsen, L.A. 1992. Methods of marking fish and shellfish. Amer. Fish. Soc., Spec. Pub. 23.

Nelson, W.G. and E. Bonsdorff. 1990. Fish predation and habitat complexity: are complexity thresholds real? J. Exp. Mar. Biol. Ecol. 141:183-194.

Neter, J., W. Wasserman and M.H. Kutner. 1990. Applied linear statistical models, 3rd ed. R.D. Irwin, Inc. Illinois.

Nichol, D.G. and E.K. Pikitch. 1994. Reproduction of darkblotched rockfish off the Oregon coast. Trans. Amer. Fish. Soc. 123(4):469-481.

Norusis, M.J. 1993. SPSS for Windows, Release 6.0. SPSS, Inc., Chicago. Illinois.

Norris, J.A. 1991. Habitat associations of juvenile rockfishes from inland marine waters of Washington state: an annotated bibliography and review. Wash. Dept. Fish. Tech. Rep. 117.

Norton, J. 1987. Ocean climate influences on groundfish recruitment in the California Current. Pages 73-99. In: Proceedings of the International Rockfish Symposium, Anchorage, Alaska, Univ. Alaska, Alaska Sea Grant Rep. 87-2.

Norton, S.F. 1991. Habitat use and community structure in an assemblage of cottid fishes. Ecol. 72(6):2181-2192.

Olla, B.L., A.J. Bejda, and A.D. Martin. 1974. Daily activity, movements, feeding and seasonal occurrence in the tautog, *Tautoga onitis*. Fish. Bull. 72(1):27-35.

Olla, B.L., A.J. Bejda, and A.D. Martin. 1975. Activity, movement and feeding behavior of the cunner, *Tautogolabrus adspersus*, and comparison of food habitats with young tautog, *Tautoga onitis*, off Long Island, New York. Fish. Bull. 73(4):895-900.

Pacific Fishery Management Council. 1989. Pacific Coast Groundfish Plan. Pac. Fish. Mgt. Concl. Portland, Oregon U.S.A.

Paine, R.T. 1966. Food web complexity and species diversity. Amer. Nat. 100:65-75.

Palsson, W.A., J.C. Hoeman, G.G. Bargmann, and D. Day. 1996. 1995 status of Puget Sound bottomfish stocks. Wash. Dept. Fish. Wildl. Tech. Rep., Olympia, WA.

Parker, N.C., A.E. Giorgi, R.C. Heidinger, D.B. Jester, Jr., E.D. Prince, and G.A. Winans, eds. 1990. Fish-marking techniques. Amer. Fish. Soc. Symp. 7.

Parrish, F.A. and J.J. Polovina. 1994. Habitat thresholds and bottlenecks in production of the spiny lobster (*Panulirus marginatus*) in the northwestern Hawaiian Islands. Bull. Mar. Sci. 54(1):151-163.

Patten, B.G. 1973. Biological information on copper rockfish in Puget Sound, Washington. Trans. Amer. Fish. Soc. 2:412-416.

Pedersen, M. and G. DiDonato. 1982. Groundfish management plan for Washington's inside waters. Wash. Dept. Fish. Prog. Rep. No. 170.

Pedersen, S.A. and F. Riget. 1992. Feeding habits of Greenland halibut, *Reinhardtius hippoglossoides*, in West Greenland waters with special emphasis on predation on shrimp and juvenile redfish. Cncl. Meet. Int. Cncl. Explor. Sea (ICES), 24 Sep. -2 Oct. 1992. (Abstract)

Pihl, L., H. Wennhage and S. Nilsson. 1994. Fish assemblage structure in relation to macrophytes and filamentous epiphytes in shallow non-tidal rocky- and soft-bottom habitats. Envir. Biol. Fish. 39:271-288.

Pinkas, L.M., M.S. Oliphant and I.L.K. Iverson. 1971. Food habitats of albacore, bluefin tuna, and bonito in California waters. Calif. Fish and Game, Fish. Bull. 152:1-105.

Prince, E.D. and D.W. Gotshall. 1976. Food of the copper rockfish, *Sebastes caurinus* Richardson, associated with an artificial reef in southern Humbolt Bay, California. Calif. Fish and Game 62(4):274-285.

Ralston, S. 1990. Progress in rockfish recruitment studies. NOAA/NMFS SW Fish. Cntr. Admin. Rep. T-90-02.

Ralston, S. and D.F. Howard. 1995. On the development of year-class strength and cohort variability in two northern California rockfishes. Fish. Bull. 93(4):710-720.

Rangeley, R.W. and D.L. Kramer. 1995. Use of rocky intertidal habitats by juvenile pollock *Pollachius virens*. Mar. Ecol. Prog. Ser. 126:9-17.

Richards, L.J. 1986. Depth and habitat distributions of three species of rockfish (*Sebastes*) in British Columbia: observations from the submersible PISCES IV. Envir. Biol. Fish. 17(1):13-21.

Richards, L.J. 1987. Copper rockfish (*Sebastes caurinus*) and quillback rockfish (*Sebastes maliger*) habitat in the Strait of Georgia, British Columbia. Can. J. Zool. 65:3188-3191.

Richards, W.J. and K.C. Lindeman. 1987. Recruitment dynamics of reef fishes: planktonic processes, settlement and demersal ecologies, and fishery analysis. Bull. Mar. Sci. 41(2):392-410.

Ricker, W.E. 1978. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Canada Bull. 191.

Riley, J.D. 1966. Liquid latex marking technique for small fish. J. de Cons. Perm. Int. Exp. de la Mer 30:354-357.

Roberts, C.M. 1997. Ecological advice for the global fisheries crisis. TREE 12(1):35-38.

Robertson, D.R. 1988. Abundances of surgeonfishes on patch-reefs in Caribbean Panama: due to settlement, or post-settlement events? Mar. Biol. 97:495-501.

Robins, C.R., R.M. Dailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea, and W.B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. 4th ed. Amer. Fish. Soc., Spec. Pub. 12, 174p.

Rosenthal, R.J., V. Moran-O'Connell, and M.C. Murphy. 1988. Feeding ecology of ten species of rockfishes (Scorpaenidae) from the Gulf of Alaska. Calif. Fish and Game 74(1):16-37.

Ryder, R.A. and S.R. Kerr. 1990. Harmonic communities in aquatic ecosystems: a management perspective. Pages 594-623, In W.L.T. van Densen , B. Steinmetz and RAH. Hugs, eds. Management of freshwater fisheries, Proceedings of a symposium organized by the European Inland Fisheries Advisory Commission, Goeteborg, Sweden, 31 May - 3 June 1988. Wageningen Netherlands PUDOC 1990.

Safran, P. and M. Omori. 1990. Some ecological observations on fishes associated with drifting seaweed of Tohoku coast, Japan. Mar. Biol. 105:395-402.

Sale, P.F. 1990. Recruitment of marine species: Is the bandwagon rolling in the right direction? Trends Ecol. Evol. 5:25-27.

Sale, P.F. 1991a. Reef fish communities: open nonequilibrial systems. Pages 564-598, In P.F. Sale, ed. The ecology of coral reef fishes. Academic Press, San Diego, California U.S.A.

Sale, P.F., ed. 1991b. The ecology of coral reef fishes. Academic Press, San Diego, California U.S.A.

Sale, P.F. and D.J. Ferrell. 1988. Early survivorship of juvenile coral reef fishes. Coral Reef Ecol. 7:117-124.

Sale, P.F., P.J. Doherty, and W.A. Douglas. 1980. Juvenile recruitment strategies and the coexistence of territorial Pomacentrid fishes. Bull. Mar. Sci. 30:147-158.

Sale, P.F. and W.A. Douglas. 1981. Precision and accuracy of visual census techniques for fish assemblages on coral patch reefs. Env. Biol. Fish. 6(3-4):333-339.

Sale, P.F. and B.J. Sharp. 1983. Corrections for bias in visual transect census of coral reef fishes. Coral Reefs 1:37-42.

Scagel, R.F. 1972. Guide to common seaweeds of British Columbia . B.C. Prov. Museum, Dept. Rec. Conser., Handbook No. 27.

Seaman, W., Jr., R.M. Buckley, and J.J. Polovina. 1989. Advances in knowledge and priorities for research, technology and management related to artificial aquatic habitats. Bull. Mar. Sci. 44(2):527-534.

Seaman, W., Jr. and L.M. Sprague. 1991. Artificial reefs for marine and freshwater applications. Academic Press, San Diego.

Shaffer, J.A., D.C. Doty, R.M. Buckley and J.E. West. 1995. Crustacean community composition and trophic use of the drift vegetation habitat by juvenile splitnose rockfish *Sebastes diploproa*. Mar. Ecol. Prog. Ser. 123:13-21.

Shanks, A.L. 1988. Further support for the hypothesis that internal waves can cause shoreward transport of larval invertebrates and fish. Fish. Bull. 86(4):703-714

Shapiro, D.Y. 1987. Inferring larval recruitment strategies from the distributional ecology of settled individuals of a coral reef fish. Bull. Mar. Sci. 41(2):289-295.

Shimizu, M., M. Kusakari, M.M. Yoklavich, G.W. Boehlert, and J. Yamada. 1991. Ultrastructure of the epidermis and digestive tract in *Sebastes* embryos, with special reference to the uptake of exogenous nutrients. Env. Biol. Fish. 30:155-163.

Shulman, M.J. 1984. Resource limitation and recruitment patterns in a coral reef fish assemblage. J. Exp. Mar. Biol. Ecol. 74:85-109.

Shulman, M.J. 1985. Recruitment of coral reef fishes: effect of distribution of predators and shelter. Ecol. 66(3):1056-1066.

Shulman, M.J. and J.C. Odgen. 1987. What controls tropical reef fish populations: recruitment or benthic mortality? An example in the Caribbean reef fish *Haemulon flavolineatum*. Mar. Ecol. Prog. Ser. 39:233-242.

Simenstad, C.A., J.S. Isakson, and R.E. Nakatani. 1977. Marine fish communities of Amchitka Island, Alaska. Pages 451-492, In M.L. Merritt and R.G. Fuller, eds., The environment of Amchitka Island, Alaska. U.S.W.R.D.A. TID 267-12.

Singer, M.M. 1985. Food habits of juvenile rockfishes (*Sebastes*) in a central California kelp forest. Fish. Bull. 83(4):531-541.

Sissenwine, M.P. 1984. Why do fish populations vary? Pages 59-94, In R.M. May ,ed., Exploitation of marine communities. Springer-Verlag, Berlin.

Smith, M.P.L. 1989. Improving multispecies rocky reef fish censuses by counting different groups of species using different procedures. Envir. Biol. Fish. 26:29-37.

Snedecor, G.W. and W.G. Cochran. 1980. Statistical methods, 7th Ed. The Iowa State University Press, Ames, Iowa.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry, 2nd ed. Wilt Freeman & Company, NY.

Stein, D. and T.J. Hassler. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) - brown rockfish, copper rockfish, and black rockfish. Bio. Rep. 82(11.113) U.S. Fish Wildlife Ser.

Steiner, W.W., J.J. Luczkovich and B.L. Olla. 1982. Activity, shelter usage, growth and recruitment of juvenile red hake *Urophycis chuss*. Mar. Ecol. Prog. Ser. 7:125-135.

Stephens, J.S., Jr., G.A. Jordan, P.A. Morris, M.M. Singer, and G.E. McGowen. 1986. Can we relate larval fish abundance to recruitment of population stability? A preliminary analysis of recruitment to a temperate reef. CalCOFI Rep. 27:65-83.

Stephens, J.S., Jr., P.A. Morris, K. Zebra, and M. Love. 1984. Factors affecting fish diversity on a temperate reef: the fish assemblage of Palos Verdes Point, 1974-1981. Env. Biol. Fish. 11:259-275.

Stimson, J.S. 1990. Density dependent recruitment in the reef fish *Chaetodon miliaris*. Envir. Biol. Fish. 29:1-13.

Strickland, R. 1983. The fertile fjord: plankton in Puget Sound. Wash. Sea Grant Pub., University of Washington Press, Seattle, Washington.

Sverdrup, H.U., M.W. Johnson, and R.H. Fleming. 1961. The Oceans. Asia Publishing House, Bombay.

Takemura, A., K. Takano, and H. Takahashi. 1995. The uptake of macromolecular materials in the hindgut of viviparous rockfish embryos. J. Fish Biol. 46:485-493.

Thrower, F.P. and W.W. Smoker. 1984. First adult returns of pink salmon tagged as emergents with binary-coded wires. Trans. Amer. Fish. Soc. 113:803-804.

Thom, R.M. and R.G. Albright. 1990. Dynamics of benthic vegetation standing-stock, irradiance, and water properties in central Puget Sound. Mar. Biol. 104:129-141.

Thurman, H.V. 1981. Introductory Oceanography. Charles E. Merrill Publishing, Columbus, Ohio. 464 pp.

Tretyak, V.L., V.A. Korzhev, and N.A. Yaragina. 1991. Trophic relations of the Barents Sea cod and their dynamics. Cncl. Meet. Inter. Cncl. Expl. Sea., Demersal Fish Comm., Copenhagen, Denmark. (Abstract)

Vermeer, K. and S.J. Westrheim. 1984. Fish changes in diets of nestling rhinoceros auklets and their implications. Pages 96-105, In D.N. Nettleship, G.A. Sanger and P.F. Springer, eds., Marine birds: their feeding ecology and commercial fisheries relationships. 8th Ann. Meet. Pac. Seabird. Grp., Seattle, Washington, U.S.A. 6-8 Jan. 1982.

Victor, B.C. 1986. Larval settlement and juvenile mortality in a recruitment-limited coral reef fish population. Ecol. Monogr. 56(2):145-160.

Wahle, R.A. and R.S. Steneck. 1991. Recruitment habitats and nursery grounds of the American lobster *Homarus americanus*: a demographic bottleneck? Mar. Ecol. Prog. Ser. 69:231-243.

Waldron, K.D. 1972. Fish larvae collected from the northeastern Pacific Ocean and Puget Sound during April and May 1967. NOAA Tech. Rep. NMFS SSRF-663.

West, J.E., R.M. Buckley, and D.C. Doty. 1994. Ecology and habitat use of juvenile rockfishes (*Sebastes* spp) associated with artificial reefs in Puget Sound, Washington. Bull. Mar. Sci. 55(2 and 3):344-350.

West, J.E., R.M. Buckley, D.C. Doty and B.E. Bookheim. 1995. Ecology and habitat use of juvenile rockfishes (*Sebastes* spp.) associated with artificial nursery habitats in Puget Sound, Washington. Pages 191-202, In Vol. 1. Proceedings Puget Sound research '95, Bellevue, Washington 1995, Puget Sound Water Quality Authority, Olympia, Washington.

Wheeler, A. 1980. Fish-algal relations in temperate waters. Pages 677-698, In J.H. Price, D.E.G. Irvine, and W.F. Farnham eds., The shore environment, Vol. 2: Ecosystems. Academic Press, London and New York.

Whipple, J.A. (ed.). 1988. Progress in rockfish recruitment studies. NOAA/NMFS SW Fish. Cntr. Admin. Rep. T-88-01.

Wilson, T.C. and S.J. Krenn. 1986. Construction and evaluation of an artificial reef designed to enhance nearshore rockfish production. Proc. Oceans '86 Conf., Wash., D.C. 2:547-551.

Wourms, J.P. 1991. Reproduction and development of *Sebastes* in the context of the evolution of piscine viviparity. Env. Biol. Fish. 30:111-126.

Wright, J.M. 1989. Detached chlorophytes as nursery areas for fish in Sulaibikhat Bay, Kuwait. Estuar. Coast. Shelf Sci. 28:185-193.

Wootton, R.J. 1990. Ecology of teleost fishes. Chapman and Hall, London. 404p.

Wyllie Echeverria, T. 1987. Thirty-four species of California rockfishes: maturity and seasonality of reproduction. Fish. Bull. 85(2):229-250.

Zar, J.H. 1984. Biostatistical analysis, 2nd ed. Prentice-Hall, Inc., New Jersey.

Appendix I. Physical profiles of BCAR and GIAR ARH and IRH, and survey quadrate coverage of the substrates.

| | Area[1] | | Depth[2] | |
|---|---|---|---|---|
| Habitat Profiles | BCAR | GIAR | BCAR | GIAR |
| ARH Total | 1,128 | 1,007 | 3-18 | 8.8-10.7 |
| North, Central, and South Habitats | 760 | | 3-16 | |
| East and West Habitats | | 682 | | 8.8-10.4 |
| Base Habitat | 368 | 325 | 16-18 | 10.4-10.7 |
| IRH Total | 1,034 | 1,166 | 7.6-18 | 8.8-10.4 |
| North, Central, and South Habitats | 760 | | 7.6-18 | |
| East and West Habitats | | 825 | | 8.8-10.4 |
| Base Habitat | 275 | 341 | 18 | 10.4 |

| | Area[1] | | Coverage | |
|---|---|---|---|---|
| Survey Quadrates | BCAR | GIAR | BCAR | GIAR |
| ARH Total | 228 | 132 | 20% | 13% |
| North, Central, and South Habitats[3] | 156 | | 21% | |
| East and West Habitats[4] | | 72 | | 11% |
| Base Habitat[5] | 72 | 60 | 20% | 18% |
| IRH Total | 216 | 144 | 21% | 12% |
| North, Central, and South Habitats[3] | 144 | | 19% | |
| East and West Habitats[4] | | 72 | | 9% |
| Base Habitat[5] | 72 | 72 | 26% | 21% |

[1] Area in $m^2$.

[2] Depth in -m MLLW.

[3] BCAR: north, central, and south habitats removed from surveys due to habitat loss; see Chapter 2.

[4] GIAR: Surveys on east habitat only; survey coverage ARH = 22%, IRH = 18%.

[5] BCAR: Base habitat only used for assessments of 1994 cohort juvenile rockfish. GIAR: ARH = 5 survey quadrates.

Appendix II. Surveys of BCAR IRH north, south, and base habitats, and adjacent sand habitat, for tagged 1991cohort juvenile rockfish.

| | | | | North Habitat | | | | South Habitat | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Time | c-y d[1] | Tag d[2] | Area[3] | n | Density[4] | No. Tag[5] | Area[3] | n | Density[4] | No. Tag[5] |
| 6/9/91 | Day | 71 | | 140 | 0 | 0 | | | | | |
| 10/14/91 | Day | 106 | 3 | 132 | 5 | 0.0379 | 0 | | | | |
| 10/22/91 | Day | 124 | 11 | 80 | 9 | 0.1125 | 0 | 160 | 20 | 0.125 | 0 |
| 12/13/91 | Day | 166 | 49 | | | | | 160 | 16 | 0.1 | 0 |
| 2/10/92 | Day | 225 | 108 | | | | | 270 | 7 | 0.0338 | 0 |
| 3/19/92 | Day | 263 | 146 | 120 | 0 | 0 | 0 | 270 | 3 | 0.011 | 0 |
| 4/20/92 | Day | 295 | 178 | 150 | 6 | 0.04 | 0 | | | | |
| 5/5/92 | Night | 310 | 193 | 75 | 10 | 0.1333 | 0 | 90 | 14 | 0.1556 | 0 |

| | | | | Base Habitat | | | | Sand Habitat | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Time | c-y d[1] | Tag d[2] | Area[3] | n | Density[4] | No. Tag[5] | Area[3] | n | Density[4] | No. Tag[5] |
| 12/13/91 | Day | 166 | 49 | 240 | 0 | 0 | 0 | | | | |
| 12/17/91 | Night | 170 | 53 | | | | | 200 | 0 | 0 | 0 |
| 2/10/92 | Day | 225 | 108 | 240 | 1 | 0.0042 | 0 | | | | |
| 3/19/92 | Day | 263 | 146 | 120 | 0 | 0 | 0 | | | | |
| 4/20/92 | Day | 295 | 178 | 60 | 0 | 0 | 0 | | | | |
| 5/5/92 | Night | 310 | 193 | 75 | 1 | 0.0133 | 0 | | | | |

1] c-y d = cohort-year day; see Table 2.3.

2] Days post-tag release.

3] Area surveyed in $m^2$.

4] Fish $m^{-2}$.

5] Number of tagged fish recovered.

Appendix III. Macrophyte and substrate profiles of ARH and IRH of BCAR and GIAR in 1994.

| BCAR ARH | | Macrophyte Coverage[1] | | | | Rock Coverage[1] | | | | Bull Kelp[2] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $t_0$ | $t_0$ | $t_{43}$ | $t_{43}$ | $t_0$ | $t_0$ | $t_{43}$ | $t_{43}$ | $t_0$ |
| Quadrate[3] | Depth[4] | % | arcs.[5] | % | arcs.[5] | % | arcs.[5] | % | arcs.[5] | No. |
| N1 | 3 | 30 | 32.21 | 20 | 26.57 | 60 | 50.77 | 70 | 56.79 | 16 |
| N2 | 4.5 | 10 | 18.43 | 20 | 26.57 | 60 | 50.77 | 80 | 63.43 | 37 |
| N3 | 15 | 0 | 0 | 0 | 0 | 50 | 45 | 50 | 45 | 0 |
| N4 | 16 | 0 | 0 | 0 | 0 | 40 | 39.23 | 40 | 39.23 | 0 |
| C1 | 4.3 | 50 | 45 | 50 | 45 | 60 | 50.57 | 60 | 50.57 | 0 |
| C2 | 6.7 | 50 | 45 | 35 | 36.27 | 100 | 90 | 70 | 56.79 | 13 |
| C3 | 8.2 | 30 | 32.21 | 20 | 26.57 | 100 | 90 | 30 | 32.21 | 60 |
| C4 | 15 | 0 | 0 | 15 | 22.79 | 90 | 71.57 | 60 | 5.057 | 35 |
| C5 | 16 | 0 | 0 | 0 | 0 | 100 | 90 | 50 | 45 | 16 |
| S1 | 4.7 | 10 | 18.43 | 0 | 0 | 40 | 39.23 | 15 | 22.79 | 8 |
| S2 | 7.6 | 10 | 18.43 | 0 | 0 | 40 | 39.23 | 0 | 0 | 1 |
| S3 | 10.4 | 0 | 0 | 0 | 0 | 30 | 32.21 | 0 | 0 | 0 |
| S4 | 13.2 | 50 | 45 | 50 | 45 | 90 | 71.57 | 90 | 71.57 | 0 |

| Quadrate[3] | Depth[4] | Quadrate[3] | Depth[4] |
|---|---|---|---|
| B1 | 16 | A1 | 15 |
| B2 | 16 | A2 | 15 |
| B3 | 16 | A3 | 15 |
| B4 | 16 | A4 | 15 |
| B5 | 16 | | |
| B6 | 16 | | |

Appendix III. Continued.

| BCAR IRH | | Macrophyte Coverage[1] | | | | Rock Coverage[1] | | | | Bull Kelp[2] |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $t_0$ | $t_0$ | $t_{41}$ | $t_{41}$ | $t_0$ | $t_0$ | $t_{41}$ | $t_{41}$ | $t_0$ |
| Quadrate[3] | Depth[4] | % | arcs.[5] | % | arcs.[5] | % | arcs.[5] | % | arcs.[5] | No. |
| C1 | 7.6 | 60 | 50.77 | 35 | 36.27 | 60 | 50.77 | 45 | 42.13 | 25 |
| C2 | 8.4 | 50 | 45 | 25 | 30 | 40 | 39.23 | 40 | 39.23 | 21 |
| C3 | 9.4 | 40 | 39.23 | 20 | 26.57 | 100 | 90 | 30 | 33.21 | 40 |
| C4 | 10.7 | 10 | 18.43 | 25 | 30 | 80 | 63.43 | 25 | 30 | 8 |
| C5 | 12.2 | 0 | 0 | 0 | 0 | 40 | 39.23 | 15 | 22.79 | 0 |
| C6 | 14.6 | 0 | 0 | 0 | 0 | 40 | 39.23 | 15 | 22.79 | 1 |
| C7 | 17 | 0 | 0 | 0 | 0 | 90 | 71.57 | 20 | 26.57 | 0 |
| S1 | 5 | 80 | 63.43 | 20 | 26.57 | 90 | 71.57 | 20 | 26.57 | 8 |
| S2 | 8 | 20 | 26.57 | 5 | 12.92 | 50 | 45 | 10 | 18.43 | 5 |
| S3 | 11 | 10 | 18.43 | 0 | 0 | 60 | 50.77 | 15 | 22.79 | 1 |
| S4 | 14 | 0 | 0 | 5 | 12.92 | 60 | 50.77 | 20 | 26.57 | 0 |
| S5 | 16 | 0 | 0 | 0 | 0 | 90 | 71.57 | 15 | 22.79 | 0 |
| B1 | 18 | | | | | | | | | |
| B2 | 18 | | | | | | | | | |
| B3 | 18 | | | | | | | | | |
| B4 | 18 | | | | | | | | | |
| B5 | 18 | | | | | | | | | |
| B6 | 18 | | | | | | | | | |

Appendix III. Continued.

| GIAR ARH | | Macrophyte Coverage[1] | |
|---|---|---|---|
| | | $t_0$ | $t_0$ |
| Quadrate[3] | Depth[4] | % | arcs.[5] |
| E1 | 8.8 | 80 | 63.43 |
| E2 | 8.8 | 80 | 63.43 |
| E3 | 9.1 | 50 | 45 |
| E4 | 9.1 | 40 | 39.23 |
| E5 | 9.7 | 40 | 39.23 |
| E6 | 10 | 40 | 39.23 |
| B1 | 10.7 | 10 | 18.43 |
| B2 | 10.7 | 20 | 26.57 |
| B3 | 10.7 | 10 | 18.43 |
| B4 | 10.7 | 10 | 18.43 |
| B5 | 10.7 | 10 | 18.43 |

| GIAR IRH | | Macrophyte Coverage[1] | |
|---|---|---|---|
| | | $t_0$ | $t_0$ |
| Quadrate[3] | Depth[4] | % | arcs.[5] |
| E1 | 9.8 | 100 | 90 |
| E2 | 9.8 | 80 | 63.43 |
| E3 | 9.8 | 90 | 71.57 |
| E4 | 10 | 90 | 71.57 |
| E5 | 10 | 90 | 71.57 |
| E6 | 10 | 90 | 71.57 |
| B1 | 10.4 | 50 | 45 |
| B2 | 10.4 | 50 | 45 |
| B3 | 10.4 | 50 | 45 |
| B4 | 10.4 | 50 | 45 |
| B5 | 10.4 | 30 | 33.21 |
| B6 | 10.4 | 30 | 33.21 |

[1] BCAR ARH: $t_0$ = 9/10/94 (c-y-d 72); $t_{43}$ = 10/23/94 (c-y d 115).
BCAR IRH: $t_0$ = 9/10/94 (c-y-d 72); $t_{41}$ = 10/21/94 (c-y d 113).
GIAR ARH and IRH: $t_0$ = 9/6/94 (c-y d 68).

[2] Number of bull kelp plants.

[3] N = north habitat; C = central habitat; S = south habitat; B = base habitat; E = east habitat; A = original artificial reef.

[4] Survey quadrate depth in -m MLLW.

[5] Arcsine transformation of %.

Appendix IV.A. Quadrate surveys on BCAR ARH for the July 1, 1994 to June 30, 1995 cohort-year.

| Date: 8/23/94 | | c-y d[1]: 54 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | N1 | N1 | N2 | N2 | C1 | C1 | C2 | C2 | C3 | Base |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. |
| Species[3] | | | | | | | | | 0 | 0 |
| Qb. juv.[4] | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | |
| Qb. s-A+A[5] | 1 | 0.083 | 5 | 0.417 | 1 | 0.083 | 4 | 0.333 | | |
| Cu. s-A+A[5] | | | 1 | 0.083 | 1 | 0.083 | | | | |
| Br. s-A+A[5] | | | 3 | 0.25 | | | | | | |

| Date: 8/24/94 | | c-y d[1]: 55 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | N1 | N1 | N2 | N2 | C1 | C1 | C2 | C2 | S1 | S1 | S2 | S2 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | | | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | 3 | 0.25 | 1 | 0.083 | | |
| Qb. s-A+A[5] | 2 | 0.167 | 3 | 0.25 | | | | | | | | |
| Cu. s-A+A[5] | | | 1 | 0.083 | 1 | 0.083 | 1 | 0.083 | 1 | 0.083 | 1 | 0.083 |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 9/10/94 | | c-y d[1]: 72 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | N1 | N2 | C1 | C1 | C2 | C3 | C3 | C4 | C5 | C5 | S1 | S2 |
| | No. | No. | No. | No. $m^{-2}$ | No. | No. | No. $m^{-2}$ | No. | No. | No. $m^{-2}$ | No. | No. |
| Species[3] | 0 | 0 | | | 0 | | | 0 | | | 0 | 0 |
| Qb. juv.[4] | | | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | | | | | | 1 | 0.083 | | |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | 1 | 0.083 | | 1 | 0.083 | | 1 | 0.083 | | |

Appendix IV.A. Continued.

| Date: 9/10/94 | | c-y d[1]: 72 | | | | |
|---|---|---|---|---|---|---|
| Quadrate[2] | S3 | S4 | B1 | B1 | B2 | B3 |
| | No. | No. | No. | No. m$^{-2}$ | No. | No. |
| Species[3] | 0 | 0 | | | 0 | 0 |
| Qb. juv.[4] | | | | | | |
| Cu. juv.[4] | | | | | | |
| Br. juv.[4] | | | | | | |
| Qb. s-A+A[5] | | | | | | |
| Cu. s-A+A[5] | | | | | | |
| Br. s-A+A[5] | | | 1 | 0.083 | | |

| Date: 10/23/94 | | c-y d[1]: 115 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | N1 | N2 | N3 | N4 | C1 | C2 | C3 | C4 | C5 | C5 | S1 | S2 |
| | No. | No. | No. | No. | No. | No. | No. | No. | No. | No. m$^{-2}$ | No. | No. |
| Species[3] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 |
| Qb. juv.[4] | | | | | | | | | 1 | 0.083 | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | | | | | | | | | |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 10/23/94 | | c-y d[1]: 115 | | | |
|---|---|---|---|---|---|
| Quadrate[2] | S3 | S4 | South | South | Base |
| | No. | No. | No. | No. m$^{-2}$ | No. |
| Species[3] | 0 | 0 | | | 0 |
| Qb. juv.[4] | | | 2 | 0.167 | |
| Cu. juv.[4] | | | | | |
| Br. juv.[4] | | | | | |
| Qb. s-A+A[5] | | | | | |
| Cu. s-A+A[5] | | | | | |
| Br. s-A+A[5] | | | | | |

Appendix IV.A. Continued.

| Date: 10/23/94 | c-y d[1]: 121 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B3 | B4 | B5 | B6 | B6 | A3 | A3 | A4 | A4 |
| | No. | No. m$^{-2}$ | No. | No. | No. | No. | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ |
| Species[3] | | | 0 | 0 | 0 | 0 | | | | | | |
| Qb. juv.[4] | 1 | 0.083 | | | | | 7 | 0.583 | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | 1 | 0.083 | | | | |
| Qb. s-A+A[5] | | | | | | | 8 | 0.667 | 8 | 0.667 | 5 | 0.417 |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | 2 | 0.167 | | | | |

| Date: 11/12/94 | c-y d[1]: 135 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B3 | B4 | B4 | B5 | B6 | B6 | A1 | A1 |
| | No. | No. m$^{-2}$ | No. | No. | No. | No. m$^{-2}$ | No. | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ |
| Species[3] | | | 0 | 0 | | | 0 | | | | |
| Qb. juv.[4] | 1 | 0.083 | | | 1 | 0.083 | | 4 | 0.333 | | |
| Cu. juv.[4] | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | | | | | 7 | 0.583 | 2 | 0.167 |
| Cu. s-A+A[5] | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | 1 | 0.083 | 1 | 0.083 |

| Date: 11/12/94 | c-y d[1]: 135 | | | | | |
|---|---|---|---|---|---|---|
| Quadrate[2] | A2 | A2 | A3 | A3 | Central | Central |
| | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ |
| Species[3] | | | | | | |
| Qb. juv.[4] | | | | | | |
| Cu. juv.[4] | | | | | | |
| Br. juv.[4] | | | | | 1 | 0.006 |
| Qb. s-A+A[5] | 10 | 0.833 | 5 | 0.417 | | |
| Cu. s-A+A[5] | | | | | | |
| Br. s-A+A[5] | | | | | | |

Appendix IV.A. Continued.

| Date: 1/8/95 | c-y d[1]: 192 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B2 | B3 | B3 | B4 | B5 | B6 | B6 | A1 | A2 | A3 | A3 |
| | No. | No. | No. | No. $m^{-2}$ | No. | No. | No. | No. $m^{-2}$ | No. | No. | No. | No. $m^{-2}$ |
| Species[3] | 0 | 0 | | | 0 | 0 | | | 0 | 0 | | |
| Qb. juv.[4] | | | 1 | 0.083 | | | 1 | 0.083 | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | | | | 3 | 0.25 | | | 3 | 0.25 |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 1/8/95 | c-y d[1]: 192 | | | |
|---|---|---|---|---|
| Quadrate[2] | A4 | A4 | North | Central |
| | No. | No. $m^{-2}$ | No. | No. |
| Species[3] | | | 0 | 0 |
| Qb. juv.[4] | | | | |
| Cu. juv.[4] | | | | |
| Br. juv.[4] | | | | |
| Qb. s-A+A[5] | 1 | 0.083 | | |
| Cu. s-A+A[5] | | | | |
| Br. s-A+A[5] | | | | |

| Date: 3/26/95 | c-y d[1]: 270 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B2 | B3 | B3 | B4 | B5 | B6 | A1 | A2 | A2 | A3 | A4 |
| | No. | No. | No. | No. $m^{-2}$ | No. | No. | No. | No. | No. | No. $m^{-2}$ | No. | No. |
| Species[3] | 0 | 0 | | | 0 | 0 | 0 | 0 | | | 0 | 0 |
| Qb. juv.[4] | | | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | 1 | 0.083 | | | | | | | | |
| Qb. s-A+A[5] | | | | | | | | | 1 | 0.083 | | |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | 1 | 0.083 | | |

## Appendix IV.A. Continued.

| Date: 3/26/95 | | c-y d[1]: 270 |
|---|---|---|
| Quadrate[2] | Central | North |
| | No. | No. |
| Species[3] | 0 | 0 |
| Qb. juv.[4] | | |
| Cu. juv.[4] | | |
| Br. juv.[4] | | |
| Qb. s-A+A[5] | | |
| Cu. s-A+A[5] | | |
| Br. s-A+A[5] | | |

| Date: 5/19/95 | | c-y d[1]: 323 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B2 | B3 | B3 | B4 | B4 | B5 | B6 | B6 | A1 | A1 |
| | No. | No. | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | 0 | 0 | | | | | 0 | | | | |
| Qb. juv.[4] | | | | | | | | 2 | 0.167 | | |
| Cu. juv.[4] | | | | | 1 | 0.083 | | | | | |
| Br. juv.[4] | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | | | | | 8 | 0.667 | 6 | 0.5 |
| Cu. s-A+A[5] | | | | | | | | | | | |
| Br. s-A+A[5] | | | 1 | 0.083 | | | | | | | |

| Date: 5/19/95 | | c-y d[1]: 323 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | A2 | A2 | A3 | A3 | A4 | A4 | Central | North |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. |
| Species[3] | | | | | | | 0 | 0 |
| Qb. juv.[4] | | | | | 2 | 0.167 | | |
| Cu. juv.[4] | | | | | | | | |
| Br. juv.[4] | | | | | | | | |
| Qb. s-A+A[5] | 1 | 0.083 | 5 | 0.417 | 7 | 0.583 | | |
| Cu. s-A+A[5] | | | | | | | | |
| Br. s-A+A[5] | 1 | 0.083 | | | | | | |

[1] c-y d = cohort-year day; see Table 2.3.
[2] N = north habitat, C = central habitat, S = south habitat, B = base habitat, A = original artificial reef; missing quadrate not surveyed; north, central, south, and base = total habitat or non-quadrate area; see Figure 2.7; No. = number of fish.
[3] Species: 0 = quadrate surveyed, no rockfish; Qb = quillback rockfish, Cr = copper rockfish, Br = brown rockfish.
[4] Juveniles: <c-y d 75 <80 mm TL; c-y d 75-100 <90 mm TL; c-y d 101-200 <100 mm TL; c-y d 201-365 <110 mm TL.
[5] s-A = sub-adults, A = adults; based on external appearance of maturity.

# Appendix IV.B. Quadrate surveys on BCAR IRH for the July 1, 1994 to June 39, 1995 cohort-year.

| Date: 8/22/94 | | c-y d[1]: 53 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | S1 | S1 | S2 | S3 | S4 | S4 | S5 | C1 | C2 | C3 | C3 |
| | No. | No. $m^{-2}$ | No. | No. | No. | No. $m^{-2}$ | No. | No. | No. | No. | No. $m^{-2}$ |
| Species[3] | | | 0 | 0 | | | 0 | 0 | 0 | | |
| Qb. juv.[4] | | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | | 1 | 0.083 | | | | 1 | 0.083 |
| Cu. s-A+A[5] | | | | | | | | | | | |
| Br. s-A+A[5] | 1 | 0.083 | | | | | | | | | |

| Date: 8/22/94 | | c-y d[1]: 53 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | C4 | C4 | C5 | C6 | C7 | C7 | B1 | B1 | B2 | B2 | B3 | B3 |
| | No. | No. $m^{-2}$ | No. | No. | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | 0 | 0 | | | | | | | | |
| Qb. juv.[4] | | | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | | 1 | 0.083 | 9 | 0.75 | 10 | 0.833 | 8 | 0.667 |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | 1 | 0.083 | | | | | 5 | 0.417 | 6 | 0.5 | 6 | 0.5 |

| Date: 9/10/94 | | c-y d[1]: 72 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | C1 | C1 | C2 | C2 | C3 | C3 | C4 | C4 | C5 | C5 | C6 | Base |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. |
| Species[3] | | | | | | | | | | | 0 | 0 |
| Qb. juv.[4] | 1 | 0.083 | 1 | 0.083 | 1 | 0.083 | 1 | 0.083 | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | | | | | | 1 | 0.083 | | |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

Appendix IV.B. Continued.

| Date: 10/21/94 | | c-y d[1]: 113 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | C1 | C2 | C2 | C3 | C4 | C4 | C5 | C6 | C7 | S1 | S1 |
| | No. | No. | No. $m^{-2}$ | No. | No. | No. $m^{-2}$ | No. | No. | No. | No. | No. $m^{-2}$ |
| Species[3] | 0 | | | 0 | | | 0 | 0 | 0 | | |
| Qb. juv.[4] | | 1 | 0.083 | | 1 | 0.083 | | | | 1 | 0.083 |
| Cu. juv.[4] | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | | | | | | | | |
| Cu. s-A+A[5] | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | |

| Date: 10/21/94 | | c-y d[1]: 113 | | | | | |
|---|---|---|---|---|---|---|---|
| Quadrate[2] | S2 | S3 | S4 | S5 | South | South | Base |
| | No. | No. | No. | No. | No. | No. $m^{-2}$ | No. |
| Species[3] | 0 | 0 | 0 | 0 | | | 0 |
| Qb. juv.[4] | | | | | 4 | 0.333 | |
| Cu. juv.[4] | | | | | | | |
| Br. juv.[4] | | | | | | | |
| Qb. s-A+A[5] | | | | | | | |
| Cu. s-A+A[5] | | | | | | | |
| Br. s-A+A[5] | | | | | | | |

| Date: 10/29/94 | | c-y d[1]: 121 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B3 | B3 | B4 | B4 | B5 | B5 | B6 | B6 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | 1 | 0.083 | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 8 | 0.667 | 8 | 0.667 | 29 | 2.417 | 36 | 3 | 30 | 2.5 | 7 | 0.583 |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | 2 | 0.167 | | | 1 | 0.083 | 4 | 0.333 | | | | |

Appendix IV.B. Continued.

| Date: 11/11/94 | | c-y d[1]: 134 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B3 | B3 | B4 | B4 | B5 | B5 | B6 | B6 |
| | No. | No. m-2 | No. | No. m-2 | No. | No. m-2 | No. | No. m-2 | No. | No. m-2 | No. | No. m-2 |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | 1 | 0.083 | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 6 | 0.5 | 11 | 0.917 | 17 | 1.417 | 43 | 3.583 | 7 | 0.513 | 28 | 2.333 |
| Cu. s-A+A[5] | | | | | 1 | 0.083 | 1 | 0.083 | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 11/11/94 | | c-y d[1]: 134 | | |
|---|---|---|---|---|
| Quadrate[2] | Central | Central | South | South |
| | No. | No. m-2 | No. | No. m-2 |
| Species[3] | | | | |
| Qb. juv.[4] | 4 | 0.333 | 2 | 0.167 |
| Cu. juv.[4] | | | | |
| Br. juv.[4] | | | | |
| Qb. s-A+A[5] | | | 2 | 0.167 |
| Cu. s-A+A[5] | | | | |
| Br. s-A+A[5] | | | | |

| Date: 1/6/95 | | c-y d[1]: 190 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B3 | B3 | B4 | B4 | B5 | B5 | B6 | B6 |
| | No. | No. m-2 | No. | No. m-2 | No. | No. m-2 | No. | No. m-2 | No. | No. m-2 | No. | No. m-2 |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | | | 1 | 0.083 | 1 | 0.083 | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 2 | 0.167 | 7 | 0.583 | 22 | 1.833 | 20 | 1.667 | 16 | 1.333 | 5 | 0.417 |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

## Appendix IV.B. Continued.

| Date: 1/6/95 | c-y d[1]: 190 | |
|---|---|---|
| Quadrate[2] | Central | South |
| | No. | No. |
| Species[3] | 0 | 0 |
| Qb. juv.[4] | | |
| Cu. juv.[4] | | |
| Br. juv.[4] | | |
| Qb. s-A+A[5] | | |
| Cu. s-A+A[5] | | |
| Br. s-A+A[5] | | |

| Date: 3/29/95 | c-y d[1]: 272 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B3 | B3 | B4 | B4 | B5 | B5 | B6 | B6 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | | | | | | | | | 1 | 0.083 | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 2 | 0.167 | 10 | 0.833 | 21 | 1.75 | 22 | 1.833 | 18 | 1.5 | 7 | 0.583 |
| Cu. s-A+A[5] | | | | | | | 1 | 0.083 | 2 | 0.167 | | |
| Br. s-A+A[5] | | | | | | | 1 | 0.083 | | | 1 | 0.083 |

| Date: 3/29/95 | c-y d[1]: 272 | | | |
|---|---|---|---|---|
| Quadrate[2] | Central | South | Base | Base |
| | No. | No. | No. | No. $m^{-2}$ |
| Species[3] | 0 | 0 | | |
| Qb. juv.[4] | | | 2 | 0.167 |
| Cu. juv.[4] | | | | |
| Br. juv.[4] | | | | |
| Qb. s-A+A[5] | | | 1 | 0.083 |
| Cu. s-A+A[5] | | | | |
| Br. s-A+A[5] | | | | |

## Appendix IV.B. Continued.

| Date: 5/18/95 | c-y d[1]: 322 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B3 | B3 | B4 | B4 | B5 | B5 | B6 | B6 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | 1 | 0.083 | 5 | 0.417 | 4 | 0.333 | 2 | 0.167 | 1 | 0.083 | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 6 | 0.5 | 24 | 2 | 34 | 2.833 | 39 | 3.25 | 35 | 2.917 | 15 | 1.25 |
| Cu. s-A+A[5] | | | | | | | 1 | 0.083 | | | | |
| Br. s-A+A[5] | 3 | 0.25 | 7 | 0.583 | 11 | 0.917 | 10 | 0.833 | 15 | 1.25 | 5 | 0.417 |

| Date: 5/18/95 | c-y d[1]: 322 | |
|---|---|---|
| Quadrate[2] | Central | Central |
| | No. | No. $m^{-2}$ |
| Species[3] | | |
| Qb. juv.[4] | 1 | 0.083 |
| Cu. juv.[4] | | |
| Br. juv.[4] | | |
| Qb. s-A+A[5] | | |
| Cu. s-A+A[5] | | |
| Br. s-A+A[5] | | |

[1] c-y d = cohort-year day; see Table 2.3.

[2] N = north habitat, C = central habitat, S = south habitat, B = base habitat, A = original artificial reef; missing quadrate not surveyed; north, central, south, and base = total habitat or non-quadrate area; see Figure 2.7; No. = number of fish.

[3] Species: 0 = quadrate surveyed, no rockfish; Qb = quillback rockfish, Cr = copper rockfish, Br = brown rockfish.

[4] Juveniles: <c-y d 75 <80 mm TL; c-y d 75-100 <90 mm TL; c-y d 101-200 <100 mm TL; c-y d 201-365 <110 mm TL.

[5] s-A = sub-adults, A = adults; based on external appearance of maturity.

## Appendix V.A. Quadrate surveys on GIAR ARH for the July 1, 1994 to June 30, 1995 cohort-year.

| Date: 9/6/94 | | c-y d[1]: 68 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E1 | E2 | E2 | E3 | E3 | E4 | E4 | E5 | E5 | E6 | E6 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | | | | | | | 2 | 0.167 | 1 | 0.083 | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 22 | 1.833 | 40 | 3.333 | 42 | 3.5 | 28 | 2.333 | 44 | 3.667 | 22 | 1.833 |
| Cu. s-A+A[5] | 2 | 0.167 | 1 | 0.083 | 5 | 0.417 | 3 | 0.25 | 5 | 0.417 | 1 | 0.083 |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 9/6/94 | | c-y d[1]: 68 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B3 | B3 | B4 | B4 | B5 | B5 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | |
| Qb. juv.[4] | 1 | 0.083 | 1 | 0.083 | 1 | 0.083 | 1 | 0.083 | | |
| Cu. juv.[4] | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | |
| Qb. s-A+A[5] | 23 | 1.917 | 9 | 0.75 | 8 | 0.667 | 7 | 0.583 | 42 | 3.5 |
| Cu. s-A+A[5] | | | | | | | | | 3 | 0.025 |
| Br. s-A+A[5] | | | | | | | | | | |

| Date: 10/24/94 | | c-y d[1]: 116 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E1 | E2 | E2 | E3 | E3 | E4 | E4 | E5 | E5 | E6 | E6 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | 1 | 0.083 | 1 | 0.083 | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 2 | 0.167 | 1 | 0.083 | 3 | 0.25 | 2 | 0.167 | 4 | 0.333 | 6 | 0.5 |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

Appendix V.A. Continued.

| Date: 10/24/94 | | c-y d[1]: 116 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B3 | B3 | B4 | B4 | B5 | B5 | East | East |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | 2 | 0.167 | 1 | 0.083 | 1 | 0.083 | | | 1 | 0.083 | 4 | 0.333 |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 8 | 0.667 | 6 | 0.5 | 3 | 0.25 | 2 | 0.167 | 11 | 0.917 | 8 | 0.667 |
| Cu. s-A+A[5] | | | 1 | 0.083 | | | | | 5 | 0.417 | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 10/24/94 | | c-y d[1]: 116 | | |
|---|---|---|---|---|
| Quadrate[2] | Base | Base | Adult | Adult |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | |
| Qb. juv.[4] | 3 | 0.05 | | |
| Cu. juv.[4] | | | | |
| Br. juv.[4] | | | | |
| Qb. s-A+A[5] | 21 | 0.35 | 21 | 0.875 |
| Cu. s-A+A[5] | | | 23 | 0.958 |
| Br. s-A+A[5] | | | | |

| Date: 11/20/94 | | c-y d[1]: 143 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E1 | E2 | E2 | E3 | E3 | E4 | E4 | E5 | E5 | E6 | E6 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | 1 | 0.083 | 1 | 0.083 | | | 1 | 0.083 | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 5 | 0.417 | 1 | 0.083 | 3 | 0.25 | | | 6 | 0.5 | 9 | 0.75 |
| Cu. s-A+A[5] | 2 | 0.167 | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

Appendix V.A. Continued.

| Date: 11/20/94 | | c-y d[1]: 143 |
|---|---|---|
| Quadrate[2] | East | East |
| | No. | No. m$^{-2}$ |
| Species[3] | | |
| Qb. juv.[4] | 1 | 0.042 |
| Cu. juv.[4] | | |
| Br. juv.[4] | | |
| Qb. s-A+A[5] | 3 | 0.125 |
| Cu. s-A+A[5] | | |
| Br. s-A+A[5] | | |

| Date: 11/21/94 | | c-y d[1]: 144 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B3 | B4 | B4 | B5 | B5 | Adult | Adult |
| | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ |
| Species[3] | | | | | 0 | | | | | | |
| Qb. juv.[4] | 1 | 0.083 | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | |
| Qb. s-A+A[5] | 9 | 0.75 | 3 | 0.25 | | 1 | 0.083 | 13 | 1.083 | 29 | 0.806 |
| Cu. s-A+A[5] | | | | | | | | 1 | 0.083 | 32 | 0.889 |
| Br. s-A+A[5] | | | | | | | | | | | |

| Date: 1/6/95 | | c-y d[1]: 205 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E2 | E2 | E3 | E3 | E4 | E5 | E5 | E6 | B1 | B1 | B2 |
| | No. | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. | No. m$^{-2}$ | No. | No. | No. m$^{-2}$ | No. |
| Species[3] | 0 | | | | | 0 | | | 0 | | | 0 |
| Qb. juv.[4] | | | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | | 1 | 0.083 | 1 | 0.083 | | 2 | 0.167 | | 1 | 0.083 | |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

Appendix V.A. Continued.

| Date: 1/6/95 | | c-y d[1]: 205 | | | | |
|---|---|---|---|---|---|---|
| Quadrate[2] | B3 | B4 | B5 | B5 | Adult | Adult |
| | No. | No. | No. | No. m-2 | No. | No. m-2 |
| Species[3] | 0 | 0 | | | | |
| Qb. juv.[4] | | | | | | |
| Cu. juv.[4] | | | | | | |
| Br. juv.[4] | | | | | | |
| Qb. s-A+A[5] | | | 2 | 0.167 | 12 | 0.5 |
| Cu. s-A+A[5] | | | 4 | 0.333 | 11 | 0.458 |
| Br. s-A+A[5] | | | | | | |

| Date: 4/23/95 | | c-y d[1]: 297 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E2 | E3 | E3 | E4 | E5 | E5 | E6 | B1 | B1 | B2 | B2 |
| | No. | No. | No. | No. m-2 | No. | No. | No. m-2 | No. | No. | No. m-2 | No. | No. m-2 |
| Species[3] | 0 | 0 | | | 0 | | | 0 | | | | |
| Qb. juv.[4] | | | 1 | 0.083 | | | | | | | 1 | 0.083 |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | | | 1 | 0.083 | | 1 | 0.083 | | 1 | 0.083 | 8 | 0.667 |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 4/23/95 | | c-y d[1]: 297 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B3 | B4 | B5 | B5 | East | East | Base | Base | Adult | Adult |
| | No. | No. | No. | No. m-2 | No. | No. m-2 | No. | No. m-2 | No. | No. m-2 |
| Species[3] | 0 | 0 | | | | | | | | |
| Qb. juv.[4] | | | 1 | 0.083 | 2 | 0.019 | 1 | 0.014 | | |
| Cu. juv.[4] | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | |
| Qb. s-A+A[5] | | | 3 | 0.25 | 2 | 0.019 | | | 36 | 1 |
| Cu. s-A+A[5] | | | | | | | | | 33 | 0.917 |
| Br. s-A+A[5] | | | | | | | | | | |

## Appendix V.A. Continued.

| Date: 5/26/95 | | c-y d[1]: 330 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E1 | E2 | E2 | E3 | E3 | E4 | E4 | E5 | E5 | E6 | E6 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | 2 | 0.167 | 2 | 0.167 | 1 | 0.083 | | | 2 | 0.167 | 1 | 0.083 |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 4 | 0.333 | 7 | 0.583 | 10 | 0.833 | 8 | 0.667 | 7 | 0.583 | 8 | 0.667 |
| Cu. s-A+A[5] | 1 | 0.083 | | | 4 | 0.333 | 1 | 0.083 | 2 | 0.167 | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 5/26/95 | | c-y d[1]: 330 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B3 | B3 | B4 | B4 | B5 | B5 | Base | Base |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | 5 | 0.416 | 8 | 0.667 | 2 | 0.167 | 2 | 0.167 | 7 | 0.583 | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 6 | 0.5 | 7 | 0.583 | | | 2 | 0.167 | 12 | 1 | 20 | 1.667 |
| Cu. s-A+A[5] | 1 | 0.083 | | | | | | | 1 | 0.083 | 2 | 0.167 |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 5/26/95 | | c-y d[1]: 330 |
|---|---|---|
| Quadrate[2] | Adult | Adult |
| | No. | No. $m^{-2}$ |
| Species[3] | | |
| Qb. juv.[4] | | |
| Cu. juv.[4] | | |
| Br. juv.[4] | | |
| Qb. s-A+A[5] | 26 | 1.083 |
| Cu. s-A+A[5] | 20 | 0.833 |
| Br. s-A+A[5] | | |

[1] c-y d = cohort-year day; see Table 2.3.

[2] E = east habitat, B = base habitat, A = original artficial reef; missing quadrate not surveyed; East and Base = total habitat or non-quadrate area; see Figure 2.8; No. = number of fish.

[3] Species: 0 = quadrate surveyed, no rockfish; Qb. = quillback rockfish, Cr. = copper rockfish, Br. brown rockfish.

[4] Juveniles: <c-y d 75 <80 mm TL; c-y d 75-100 <90 mm TL; c-y d 101-200 <100 mm TL; c-y d 201-365 <110 mm TL.

[5] s-A = sub-adults, A = adults; based on external appearance of maturity.

Appendix V.B. Quadrate surveys on GIAR IRH for the July 1, 1994 to June 30, 1995 cohort-year.

| Date: 9/6/94 | | c-y d[1]: 68 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E1 | E2 | E2 | E3 | E3 | E4 | E4 | E5 | E5 | E6 | E6 |
| | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | | | | | | | 1 | 0.083 | | | 1 | 0.083 |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 5 | 0.417 | 12 | 1 | 5 | 0.417 | 16 | 1.333 | 2 | 0.167 | 10 | 0.833 |
| Cu. s-A+A[5] | | | 1 | 0.083 | 7 | 0.583 | 1 | 0.083 | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 9/6/94 | | c-y d[1]: 68 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B4 | B4 | B5 | B5 | B6 | B6 |
| | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ |
| Species[3] | | | | | | | | | | |
| Qb. juv.[4] | 2 | 0.167 | 1 | 0.083 | 1 | 0.083 | | | 1 | 0.083 |
| Cu. juv.[4] | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | |
| Qb. s-A+A[5] | 19 | 1.583 | 6 | 0.5 | 17 | 1.417 | 17 | 1.417 | 29 | 2.417 |
| Cu. s-A+A[5] | | | | | 1 | 0.083 | 3 | 0.25 | 2 | 0.167 |
| Br. s-A+A[5] | | | | | | | | | | |

| Date: 10/24/94 | | c-y d[1]: 116 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E2 | E2 | E3 | E3 | E4 | E5 | E5 | E6 | E6 | B1 | B1 |
| | No. | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ |
| Species[3] | 0 | | | | | 0 | | | | | | |
| Qb. juv.[4] | | | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | | 4 | 0.333 | 1 | 0.083 | | 1 | 0.083 | 1 | 0.083 | 1 | 0.083 |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

Appendix V.B. Continued.

| Date: 10/24/94 | | c-y d[1]: 116 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B2 | B2 | B3 | B4 | B4 | B5 | B5 | B6 | B6 | East | East |
| | No. | No. m$^{-2}$ | No. | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ |
| Species[3] | | | 0 | | | | | | | | |
| Qb. juv.[4] | 2 | 0.167 | | 3 | 0.25 | 1 | 0.083 | 1 | 0.083 | 2 | 0.083 |
| Cu. juv.[4] | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | 5 | 0.417 | | | | | | |
| Cu. s-A+A[5] | | | | 2 | 0.167 | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | |

| Date: 10/24/94 | | c-y d[1]: 116 |
|---|---|---|
| Quadrate[2] | Base | Base |
| | No. | No. m$^{-2}$ |
| Species[3] | | |
| Qb. juv.[4] | 1 | 0.042 |
| Cu. juv.[4] | | |
| Br. juv.[4] | | |
| Qb. s-A+A[5] | 5 | 0.208 |
| Cu. s-A+A[5] | | |
| Br. s-A+A[5] | | |

| Date: 11/20/94 | | c-y d[1]: 143 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E2 | E2 | E3 | E3 | E4 | E4 | E5 | E5 | E6 | E6 |
| | No. | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ | No. | No. m$^{-2}$ |
| Species[3] | 0 | | | | | | | | | | |
| Qb. juv.[4] | | | | | | | | 1 | 0.083 | 1 | 0.083 |
| Cu. juv.[4] | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | |
| Qb. s-A+A[5] | | 3 | 0.25 | 1 | 0.083 | 2 | 0.167 | 2 | 0.167 | 5 | 0.417 |
| Cu. s-A+A[5] | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | |

Appendix V.B. Continued.

| Date: 11/20/94 | | c-y d[1]: 143 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B3 | B4 | B4 | B5 | B5 | B6 | B6 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | 0 | | | | | | |
| Qb. juv.[4] | 1 | 0.083 | | | | 2 | 0.167 | | | | |
| Cu. juv.[4] | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | |
| Qb. s-A+A[5] | 4 | 0.333 | 4 | 0.333 | | 1 | 0.083 | 4 | 0.333 | 4 | 0.333 |
| Cu. s-A+A[5] | 1 | 0.083 | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | |

| Date: 1/21/95 | | c-y d[1]: 205 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E2 | E3 | E4 | E5 | E6 | E6 | B1 | B2 | B3 | B4 | B5 |
| | No. | No. | No. | No. | No. | No. | No. $m^{-2}$ | No. | No. | No. | No. | No. |
| Species[3] | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Qb. juv.[4] | | | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | | | 1 | 0.083 | | | | | |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 1/21/95 | | c-y d[1]: 205 |
|---|---|---|
| Quadrate[2] | B6 | |
| | No. | |
| Species[3] | 0 | |
| Qb. juv.[4] | | |
| Cu. juv.[4] | | |
| Br. juv.[4] | | |
| Qb. s-A+A[5] | | |
| Cu. s-A+A[5] | | |
| Br. s-A+A[5] | | |

Appendix V.B. Continued.

| Date: 4/23/95 | | c-y d[1]: 297 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E2 | E3 | E4 | E5 | E6 | E6 | B1 | B2 | B3 | B4 | B5 |
| | No. | No. | No. | No. | No. | No. | No. $m^{-2}$ | No. | No. | No. | No. | No. |
| Species[3] | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | 0 |
| Qb. juv.[4] | | | | | | | | | | | | |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | | | | | | 1 | 0.083 | | | | | |
| Cu. s-A+A[5] | | | | | | | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 4/23/95 | | c-y d[1]: 297 |
|---|---|---|
| Quadrate[2] | B6 | |
| | No. | |
| Species[3] | 0 | |
| Qb. juv.[4] | | |
| Cu. juv.[4] | | |
| Br. juv.[4] | | |
| Qb. s-A+A[5] | | |
| Cu. s-A+A[5] | | |
| Br. s-A+A[5] | | |

| Date: 6/8/95 | | c-y d[1]: 343 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | E1 | E1 | E2 | E2 | E3 | E3 | E4 | E4 | E5 | E5 | E6 | E6 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | | | 4 | 0.333 | | | | | | | 4 | 0.333 |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 3 | 0.25 | 9 | 0.75 | 4 | 0.333 | 6 | 0.5 | 2 | 0.167 | 3 | 0.25 |
| Cu. s-A+A[5] | | | | | 1 | 0.083 | | | | | | |
| Br. s-A+A[5] | | | | | | | | | | | | |

Appendix V.B. Continued.

| Date: 6/8/95 | | c-y d[1]: 343 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quadrate[2] | B1 | B1 | B2 | B2 | B3 | B3 | B4 | B4 | B5 | B5 | B6 | B6 |
| | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ | No. | No. $m^{-2}$ |
| Species[3] | | | | | | | | | | | | |
| Qb. juv.[4] | 3 | 0.25 | 2 | 0.167 | | | | | | | 2 | 0.167 |
| Cu. juv.[4] | | | | | | | | | | | | |
| Br. juv.[4] | | | | | | | | | | | | |
| Qb. s-A+A[5] | 17 | 1.417 | 17 | 1.417 | 2 | 0.167 | 26 | 2.167 | 9 | 0.75 | 4 | 0.333 |
| Cu. s-A+A[5] | | | 1 | 0.083 | | | | | 2 | 0.167 | 2 | 0.167 |
| Br. s-A+A[5] | | | | | | | | | | | | |

| Date: 6/8/95 | | c-y d[1]: 343 |
|---|---|---|
| Quadrate[2] | East | East |
| | No. | No. $m^{-2}$ |
| Species[3] | | |
| Qb. juv.[4] | 3 | 0.136 |
| Cu. juv.[4] | | |
| Br. juv.[4] | | |
| Qb. s-A+A[5] | 20 | 0.909 |
| Cu. s-A+A[5] | | |
| Br. s-A+A[5] | | |

1] c-y d = cohort-year day; see Table 2.3.

2] E = east habitat, B = base habitat, A = original artficial reef; missing quadrate not surveyed; East and Base = total habitat or non-quadrate area; see Figure 2.8; No. = number of fish.

3] Species: 0 = quadrate surveyed, no rockfish; Qb. = quillback rockfish, Cr. = copper rockfish, Br. = brown rockfish.

4] Juveniles: <c-y d 75 <80 mm TL; c-y d 75-100 <90 mm TL; c-y d 101-200 <100 mm TL; c-y d 201-365 <110 mm TL.

5] s-A = sub-adults, A = adults; based on external appearance of maturity.

Appendix VI. Number and lengths of quillback rockfish and copper rockfish from previous cohorts on BCAR and GIAR during the 1994 cohort-year.

BCAR ARH + Original Artificial Reef

Quillback Rockfish

| c-y d[1] | n | Range[2] | Avg.[2] | SD[2] |
|---|---|---|---|---|
| 75 | 1 |  | 150 |  |
| 121 | 21 | 120-190 | 153.3 | 22.4 |
| 135 | 24 | 140-200 | 164.2 | 22.4 |
| 192 | 8 | 120-200 | 167.5 | 32 |
| 269 | 1 |  | 160 |  |
| 323 | 24 | 120-200 | 159.2 | 21 |

Copper Rockfish

| c-y d[1] | n | Range[2] | Avg.[2] | SD[2] |
|---|---|---|---|---|
| 75 | 4 | 130-140 | 137.5 | 5 |
| 121 | 2 | 120 | 120 | 0 |
| 135 | 2 | 120-150 | 135 | 21.2 |

BCAR IRH

Quillback Rockfish

| c-y d[1] | n | Range[2] | Avg.[2] | SD[2] |
|---|---|---|---|---|
| 75 | 1 |  | 160 |  |
| 121 | 126 | 110-200 | 140.6 | 24.6 |
| 134 | 122 | 110-200 | 160.9 | 19.5 |
| 190 | 75 | 135-210 | 173.7 | 20 |
| 272 | 80 | 120-240 | 164.8 | 21 |
| 322 | 45 | 120-200 | 149.3 | 19.2 |

Copper Rockfish

| c-y d[1] | n | Range[2] | Avg.[2] | SD[2] |
|---|---|---|---|---|
| 75 | 2 | 130 | 130 | 0 |
| 121 | 1 |  | 150 |  |
| 134 | 2 | 180-200 | 190 | 14.1 |
| 272 | 3 | 150-180 | 170 | 17.3 |
| 322 | 1 |  | 220 |  |

Appendix VI. Continued.

GIAR ARH + Original Artificial Reef

Quillback Rockfish

| c-y d[1] | n | Range[2] | Avg.[2] | SD[2] |
|---|---|---|---|---|
| 68 | 319 | 90-180 | 104.8 | 19.1 |
| 116 | 70 | 110-170 | 122.4 | 14 |
| 144 | 64 | 110-200 | 140.5 | 24.5 |
| 200 | 16 | 110-200 | 148.8 | 26.8 |
| 297 | 5 | 120-150 | 128 | 13 |
| 330 | 59 | 120-220 | 137.8 | 21.9 |

Copper Rockfish

| c-y d[1] | n | Range[2] | Avg.[2] | SD[2] |
|---|---|---|---|---|
| 68 | 20 | 110-200 | 142.5 | 23.4 |
| 116 | 6 | 120-200 | 151.7 | 30.6 |
| 144 | 31 | 150-200 | 184.2 | 19.1 |
| 200 | 13 | 140-220 | 172.3 | 29.2 |
| 330 | 12 | 140-220 | 170.8 | 22.7 |

GIAR IRH

Quillback Rockfish

| c-y d[1] | n | Range[2] | Avg.[2] | SD[2] |
|---|---|---|---|---|
| 68 | 83 | 90-110 | 98 | 9.8 |
| 116 | 16 | 110-160 | 121.3 | 15.9 |
| 143 | 21 | 110-160 | 128.6 | 13.1 |
| 205 | 1 | | 170 | |
| 343 | 24 | 120-200 | 135.8 | 21.7 |

Copper Rockfish

| c-y d[1] | n | Range[2] | Avg.[2] | SD[2] |
|---|---|---|---|---|
| 68 | 15 | 140-180 | 164.7 | 14.6 |
| 116 | 2 | 120-150 | 135 | 21.2 |
| 143 | 1 | | 150 | |
| 343 | 1 | | 180 | |

[1] c-y d = cohort-year day; see Table 2.3.

[2] Total length in mm.

# VITA

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