FRI-UW-9123
December 1991

EFFECTS OF ESTUARINE HABITAT MODIFICATIONS ON ANADROMOUS SALMONIDS: A LITERATURE SURVEY

C.A. SIMENSTAD, K.L. FRESH, J. FLEMMA, AND D. CLARKE

COASTAL ECOLOGY GROUP
U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

FRI-UW-9123
December 1991

WETLAND ECOSYSTEM TEAM
FISHERIES RESEARCH INSTITUTE
UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

EFFECTS OF ESTUARINE HABITAT MODIFICATIONS ON ANADROMOUS SALMONIDS: A LITERATURE SURVEY

C.A. SIMENSTAD, K.L. FRESH,[1] J. FLEMMA,[2] AND D. CLARKE[3]

COASTAL ECOLOGY GROUP
U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

Approved

Submitted 5-1-92 R. C. Francis
Director

[1]Washington Department of Fisheries, Research and Development.

[2]School of Marine Affairs.

[3]U.S. Army Corps of Engineers, Waterways Experimental Station.

CONTENTS

LIST OF TABLES

KEY WORDS

estuarine habitat, salmonids, modification effects

INTRODUCTION

BACKGROUND

Anadromous salmon and trout pass through and reside in estuaries at various periods during their complex life histories. Juvenile Pacific salmon (*Oncorhynchus* spp.) and steelhead (rainbow) trout (*O. mykiss*) spend from just a few days to many months in estuarine habitats before completing their migration to the North Pacific Ocean. Upon their return as adults, they may also reside in estuaries for extended periods, depending upon when freshwater conditions are such that the fish can move upstream to spawn. Other anadromous salmonids (e.g., Dolly Varden, *Salvelinus malma*) may occupy estuaries for lengthy periods during marine residence.

The notion that estuarine habitats are critical nursery grounds for juvenile salmon hinges upon inferred evidence of use such as the absence or presence of juvenile salmon and the composition of their diets. Largely on the basis of this evidence, investigators have assumed that total survival of salmon is enhanced as a result of estuarine usage. The importance of estuarine use in terms of critical population determinants such as survival to reproduction (e.g., Levings et al. 1989) been tested in only a few instances, and these rare experiments have not evaluated the role of specific estuarine habitats or features nor the mechanisms which affect survival. Thus, until the use of estuarine habitats can be linked directly to the fitness and ultimate survival of fishes that used the habitats, management of these habitats and of the fish and wildlife that depend upon them will lack the criteria necessary to evaluate the impacts of development and habitat restoration.

APPROACH

The primary objective of this project is to develop a protocol for quantitatively evaluating the impacts of various estuarine habitat modifications on anadromous salmonids in the Pacific Northwest. The protocol will help identify the information needed by environmental managers to evaluate the potential impacts of estuarine habitat modification. Thus, this protocol will be a tool to *assist* decision making and not be *the* decision making process itself, because habitat modification impacts are merely one of a variety of impacts that will determine the option chosen by the decision maker.

We propose to experimentally test differences in the survival fitness of juvenile salmon relative to their use of natural versus restored/created estuarine habitats. Fitness will be measured in this approach as residence time and growth under three estuarine habitat use treatments (1–no use, 2–created habitat use, and 3–natural habitat use). In a subsequent phase of the study, we intend to test the assumption that residence time and growth in estuarine habitats derive results in total survival of adult salmon.

The project consists of two elements, riverine and estuarine systems. The ecological effects of habitat modifications in freshwater systems were evaluated by the Corps of Engineers' Waterways Experiment Station (CEWES) and are considered separately. Impacts of habitat modifications in estuarine (and marine, if applicable) systems were evaluated by the Wetland Ecosystem Team of the Fisheries Research Institute, University of Washington and Washington Department of Fisheries.

Estuarine systems were defined as those where seawater is measurably diluted by freshwater, corresponding to Pritchard's (1967) definition of an estuary as ". . . *a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably* *diluted with freshwater derived from land drainage.*" Marine habitats, i.e., those dominated almost exclusively by seawater, were not included unless they were located within the confines of an estuarine embayment. Tidal freshwater habitats (i.e., lower stretches of rivers under the influence of tidal action but not inundated by saltwater) were also considered within the purview of the estuarine assessment.

There are four phases to the study: Phase I consists of reviewing and evaluating existing literature and identifying the impacts of habitat modifications. In Phase II, we will develop sampling techniques and experiments to test the protocol. During Phase III, we will conduct field surveys of selected components of the evaluation protocol. We will use the information gathered in these experiments to address major gaps in the mechanistic understanding of how estuarine habitat modifications affect anadromous salmonids in the Pacific Northwest. Ultimately, in Phase IV, we will evaluate and publish protocol results. We also propose to revise the evaluation protocol to allow for application to other regions and anadromous fishes.

This report describes the approach and methodology to Phase I.

OBJECTIVES OF PHASE I

The primary task of Phase I was to review literature dealing with the quantitative assessment of impacts. This review was initiated by conducting computer searches of commercial literature databases and screening these citations to form a base of relevant references. Subsequently, citations were to be further evaluated in a systematic and standardized fashion and then used to design a methodology for developing the protocol. The specific objectives of Phase I were as follows:

1. Review and evaluate both primary and secondary literature;
2. develop standardized, objective criteria that are comprehensive over species and regions;
3. use the literature review to conduct a preliminary assessment of major information needs;
4. discuss how research could address critical gaps;
5. identify databases that could be used to test some theories at the estuary/stock level; and
6. develop an assessment protocol based upon literature results.

The intent of the literature review was not to rigorously critique individual studies. We recognize that many of the studies were not designed to statistically test the effect of specific habitat modifications upon fish survival. Moreover, most studies are limited by funding constraints that inhibit the level of effort required to conduct rigorous experiments. Thus, our goal in reviewing these studies was to answer the broader question: Is there an accumulation of scientific literature that provides strong evidence that estuarine habitat modifications affect salmonid survival.

METHODS

LITERATURE SEARCH METHODOLOGY

Each database was searched for appropriate sources using an identical strategy. First, all fields in the database were searched for:

1. *Salmo*[1] or steelhead or *Oncorhynchus*; and
2. estuary or estuarine or estuaries or tidal.

This provided a list of potential sources that varied in size according to the database. The abstract of each of these records was then read to determine its specific relevance to this study. Relevance criteria included study site location and the mention of one or more of the habitat modifications being considered in this study (see list that follows).

The database was also searched using:

1. *Salmo* or steelhead or *Oncorhynchus*; and
2. each of the individual habitat modification key words (Table 1).

Except in a few isolated cases, this secondary search failed to yield any new records.

In categorizing habitat modifications, a key word list was generated using an initial list of 16 words supplied by CEWES. This list was cross-referenced and updated, using the thesaurus, for each database.

LITERATURE SOURCES

Searching Commercial Databases

Three different databases were searched to derive a preliminary list of sources: *Aquatic Sciences and Fisheries Abstracts* (ASFA), *Selected Water Resources Abstracts* (SWRA), and the *National Technical Information Service* (NTIS). All three are available on compact disc in the University of Washington library system.

ASFA is a comprehensive database of literature dating back to 1982 on science, technology, and management of marine and freshwater environments and resources. The international sources monitored include about 5,000 primary journals and a wide variety of other source documents that emphasize marine science, including books, monographic series, conference proceedings, and technical research reports.

The SWRA database is produced by the Geological Survey, U.S. Department of the Interior, and includes abstracts of pertinent monographs, journal articles, reports, and other publications. This database emphasizes environmental quality and drinking water issues dating back to 1968.

NTIS' Government Reports: Announcements and Index is produced by the U.S. Department of Commerce. It is the central source for public sale of U.S. government-sponsored research, development, and engineering reports. Sources dating back to 1985 are available on compact disc. To search the database for documents published prior to 1985 required going on-line with NTIS.

Mail Requests From Experts

After an initial database of relevant records had been created, the next step was to review these documents were reviewed and their bibliographies used to find other relevant sources to add to the database. In addition, certain salmonid ecologists considered to be experts in the field of estuarine studies (see Appendix A) were solicited for possible references.

---

[1]All possible variations of the word were considered in the search.

Table 1. List of categories used to characterize literature on the effects of estuarine habitat modifications on anadromous fishes in the Pacific Northwest.

Bank modification
- stabilization
- dike
- levee
- embankment
- revetment
- bulkhead
- rip rap
- training walls

Seabed modification
- dredging (incl. dredge, dredge spoil, etc.)
- excavation
- trenching
- rip channel
- sea channel
- navigation channel
- canal
- wetland drainage
- log storage
- intake channel
- filling/dredge disposal

Flow control
- jetty
- weir
- hydraulic structure
- tidegate
- dam
- flood control
- salinity intrusion
- freshwater diversion

Erosion control
- seawall
- groin (groyne)
- coast defense
- coastal erosion

Artificial harbors
- marina
- breakwater
- port installations
- recreational waters
- impoundment

Habitat improvement
- artificial reef
- artificial islands

CATEGORIZING INFORMATION

As the search progressed, it became obvious that there were papers that did not directly address the impacts of habitat manipulation on salmonids but were still relevant to impact assessment. These papers were important to include in the database, but they needed to be distinguished from papers dealing with direct impacts, which would be further analyzed. Consequently, we decided to break the papers into four categories: Direct, Indirect, Background, and Outside.

Direct

Direct references are papers that detail direct impacts of a particular habitat modification on salmonids. Papers discussing direct impacts are further categorized, as described later in this report. A few papers were evaluated more than once because they studied more than one habitat or habitat modification and were essentially considered to be a multiple-topic or multiple-treatment study.

A small number of direct references were summary reports of studies already listed in the database. Unlike the other direct references, these summary reports were not subjected to the analysis of data. (These reports are indicated by a ** after their title.)

Indirect

Indirect references discuss habitat manipulation and impacts but do not mention impacts to salmonids specifically. Instead, they may mention impacts to prey species or the environment.

Background

Background references are papers describing environmental requirements and behavioral characteristics of various salmonid species. Such background information is integral to determining impact assessment. However, background papers listed in this report are not meant to be all-inclusive. A separate search was not conducted on background papers, and the ones cited here were the extraneous results of our search for direct references.

Outside

Outside citations are papers that discuss the impacts of habitat manipulation on salmonid species in geographical regions outside of the Pacific Northwest.

Evaluation of Literature Citations Dealing with Direct Impacts

Only studies designated as **direct** were systematically evaluated; **indirect**, **background** or **outside** studies were not evaluated, but they are included (except for Outside citations) in Appendix B.2 and B.3.

Assessing each study involved (1) describing the general study information, (2) categorizing the alterations that were the intent of the studies vs. those that were actually documented in the studies, (3) similarly comparing the responses studied versus those documented, (4) assessing the validity of the experimental design, and (5) evaluating the results and the soundness of the interpretations derived from the data.

Each of the papers considered to deal with direct impacts was evaluated in a systematic and standardized fashion. The form used to evaluate each paper is reproduced in Appendix C. We made an important distinction in evaluating both the studies and the impacts: the *alterations* that occurred as a result of habitat modifications versus the *responses* by the fish to those alterations. In addition, instead of a binary, "yes/no" format, impacts were evaluated as having either a **direct**, **indirect**, **no**, or **benign** effect. In describing the intent of a study, **direct** means that the parameter was intentionally studied; in the case of impacts, **direct** indicates that the relationship between a significant effect and the cause of the effect were unambiguous. An **indirect** study means that the parameter was not intentionally studied, but that observations were made; an **indirect** impact means that there was a correlative determination or inference of impacts with respect to that parameter. **No** (parameter) in terms of the study means that the parameter was not studied or it was not known if the parameter was studied or impacted; **benign**, on the other hand, signifies conclusive evidence that the parameter was *not* impacted by habitat manipulation. Additional information on the categories of information used in the evaluation and their definition is included in Appendix C.

Design of Database

We used a commercially available relational database computer program to organize, store, retrieve, and manipulate (e.g., sort, print reports, etc.) both the literature citations retrieved and the data generated from the evaluation of each study. *RBase for DOS*™ was used because of our familiarity with its operation and because it appeared to offer the most options and the least limitations to the design of this project. The advantage of a relational database is that common parameters among the literature studies, data produced from the evaluation of the studies, and any subsequent information generated as a part of the protocol or studies to develop/test the protocol can be used to link these diverse data sets.

Information from the various commercial literature searches was easily imported into *RBase* and organized into the database structure. Data from the evaluation of the pertinent (**direct**) literature studies were input directly into the database. When compiling the results, data retrieved and sorted in *RBase* were exported to a word processing (e.g., Microsoft *Word*) or spreadsheet (e.g., Microsoft *Excel*) program for more efficient formatting and printing.

RESULTS

Composition of Database

Only 24 citations met the criteria established to consider them **direct** citations. In several instances, multiple citations addressed the same study. Where the content was determined to be exactly the same, the most recent or comprehensive citation was evaluated. In order to list all relevant literature, however, all citations have been listed in the bibliography of **direct** literature citations (Appendix B.1). Twelve citations were classified as **indirect** and 28 as **background** sources of information.

Categories of Estuarine Systems and Locations

A detailed summarization of the evaluation data is included in Appendix D. Geographic sources of the published studies on estuarine habitat modifications were predominantly (54.2%) concentrated in the region of Puget Sound and the Strait of Georgia, one third from British Columbia, and the remainder from northern California. No studies were reported from either the Washington-Oregon coasts or from Alaska.

Chum, *O. keta* (66.7%), and chinook, *O. tshawytscha*, salmon (45.8%) were the species most often studied. Other species included coho (*O. kisutch*), pink (*O. gorbuscha*), and sockeye (*O. nerka*) salmon in relative order of emphasis. It is noteworthy that this list approximates the order of the reported level of dependency upon estuarine habitats for these species. Additionally important was that we found *no* published studies that addressed the consequences of estuarine habitat modifications on anadromous rainbow (steelhead) or cutthroat (*Salmo clarki*) trout.

Approximately half of the studies (45.8-50.0%) focused on fry or juvenile salmon, respectively. There were no studies on smolts and only one on adult salmon.

Many citations did not report the actual habitat sampled during the study. Most of those that did, however, were located in intertidal and neritic habitats, whereas only a few occurred throughout the estuary or in subtidal habitats. Habitat substrates were predominantly fine-grained—either sand or mixed-fine to mud—or in the water column. Only two were in coarse sediments, e.g., gravel or mixed coarse. One-third of the studies did not report the study habitat substrate.

A major portion (41.7%) of the studies encompassed a complex of habitat exposures, located predominantly in channels and sloughs, and less so in partly enclosed embayments. Three of the studies did not report the energy level of the study habitat. Almost all (95.8%) studies took place under mixohaline conditions; the remainder in the oceanic, euhaline end of the estuary.

Over half (54.2%) of the published studies did not include habitat-associated vegetation. Of those that did, five included a diversity of vegetation types, three were conducted in seagrass habitats, and three were conducted in low and high emergent marshes.

MODIFICATIONS

Estuarine modifications studied most often were dredging or associated modifications (e.g., channel dredging and filling, or dredged material disposal) and port installation. The effects of freshwater diversion, and bank and seabed modifications (i.e., riprap, training walls, log storage, and excavation) on anadromous fishes comprised the few other studies. No published reports were available on the effects of any aspect of erosion control on anadromous fishes. Habitat improvement involved only four studies: two of artificial island construction and one each of wetland and artificial reef construction.

Habitat modifications were relatively evenly divided among 0-1, 1-5 and >5 year post-modification periods. Only two studies had been conducted on older (>25 years) modifications.

PURPOSE

Three quarters of these studies were conducted to measure resource impacts. In comparison, habitat mitigation was the explicit objective of one-fourth of these studies and was not involved in any of the other studies. Less than half of the studies involved pre-modification monitoring. The vast majority (80%) of the studies were restricted to post-modification (in the absence of a pre-modification baseline) assessments.

IMPACTS

Alterations

Comparability between the alterations studied and documented is strong; that is, those alterations considered to be the inherently obvious product of estuarine habitat modifications were usually found. Geomorphological (33.3%), ecological (fish prey resources, 25%; primary production, 16.7%), and hydrological (20.8%) alterations were the more common foci of study; hydrology (20.8%) and fish prey resources (16.7%) were most often documented. Turbidity, pollutants, light, and predators were studied infrequently, and temperature, predators, and competitors were never documented. Pollutants and ecological alterations were also of primary interest in terms of *indirect* effects studied, and, in addition to habitat morphology, were the most often documented impacts. Salinity alteration was never considered nor documented as an *indirect* impact.

Responses

Comparability between the responses studied and documented was also high. Fish abundance and short-term survival were the most frequent response variables studied, and fish abundance, distribution, and short-term survival were the primary variables shown to respond directly to habitat modification. Conversely, several of the studies found no effect on short-term survival, and at least one study indicated no effect on abundance, physiology, feeding, and distribution. Altered fish abundance, growth rate, age structure, distribution, and residence time were also studied as indirect responses of habitat modification, corresponding to documented indirect responses in residence time, fish growth, feeding, and migration rate. Fish schooling was the only identified variable not studied directly.

Responses to Alterations

The distribution of responses among estuarine alterations (Appendix E) indicated that the most common impact (i.e., ~1/3 of the studies) was associated with changes in fish abundance in response to changes in habitat morphology. Other impacts reported in 12.5–16.7% of these studies were identified based upon (1) fish abundance associated with changes in hydrology, (2) short-term survival associated with turbidity, and (3) pollutants, and (4) fish distribution changes associated with changes in habitat morphology.

EVALUATION OF STUDIES

In contrast to the stated results, we found that few of these studies could be applied rigorously as inferential evidence of the impact of estuarine habitat modification on anadromous salmonids. Only 4 (16.7%) of the 24 studies explicitly stated a scientific hypothesis (Appendix E). This occurred in two studies for responses in fish abundance, and in one each for responses in short-term survival, physiology, feeding and distribution; and for alterations in pollutant levels and prey resources.

Although a majority of the studies (15) used statistical testing, we determined that an appropriate statistical sampling design was applicable in only two cases. Replication was also common (70.8% of the studies), but we could not determine the power of the sampling design given the stated scales of replication. Responses in fish abundance, and to a lesser degree short-term survival and feeding, were usually the only variable addressed in these statistical designs, and no design *explicitly* related the response to the alteration in an unambiguous fashion.

Most (75.0%) studies employed appropriate sampling durations or frequencies over space and time for the alterations and responses they were sampling, but few provided any data elucidating interannual variation for a specific alteration-response relationship.

BOTTOM LINES

The "bottom line" we ascribed for each of these studies formed a concise statement of the applicability of the study and its results to the overall question, and a statement of the reason why it was inapplicable, if so. In our opinion, these studies do not form a body of evidence testing the impacts of estuarine habitat modification on salmonid fishes. The reasons for this conclusion are as follows:

- Seldom are baseline data on the habitat, fish, and indirect parameters obtained prior to an alteration and coincident with an appropriate control;
- obvious responses to a habitat alteration are highly dynamic, suggesting the altered habitat is still in a transitional ("successional") state and not in an "equilibrium" condition that might indicate the *net*, long-term impact;
- there is no direct test of alteration-response relationships that excludes other, alternative explanations for the observed response;
- the general lack of statistical rigor limits the inferential use to generalize the results or to detect and interpret measurable differences; and
- the consequence of estuarine alterations is almost never applied to the total survival of the fish over their life history to reproduction, thus eliminating any comparison to compensatory survival subsequent to estuarine residence.

DISCUSSION

APPLICABILITY OF LITERATURE TO IMPACTS OF ESTUARINE HABITAT ALTERATION

Our expectation when we began this project was that an extensive database existed concerning impacts of habitat modifications to salmonids. This is not the case. We could find only 24 studies that *directly* assessed the impacts of marine or estuarine habitat modifications on salmonids. In lieu of direct studies of impacts, most studies of the impacts of habitat modifications in nearshore areas have relied solely upon indirect information. This consists of using such information as can be *inferred* from indirect studies of juvenile salmon ecology or even those of other species (i.e., non-salmonids) to assess impacts. The lack of direct studies of impacts is surprising given the length of time that development in nearshore areas has been occurring (>100 years).

We suggest that the lack of information on impacts of habitat modifications may be a function of biologists' changing perceptions about what factors are critical to the survival of salmonids. Historically, freshwater factors were generally believed to be the most critical determinants of survival and marine factors were considered to be of minor importance. Only recently have we come to appreciate that the early marine period of juvenile salmonids may have a major influence on the number of adult returns of some stocks. As a result, developments in nearshore marine and estuarine habitats have come under increasing scrutiny in recent years and have been the focus of an increasing number of directed research studies. Thus, we conclude that many more direct studies of impacts will be needed to develop an adequate database on the affects of nearshore marine habitat modifications on juvenile salmonids.

Our review of the literature indicated that the focus of most studies of estuarine modifications has been limited to only several types of developments. Only port installation and dredging have been the subject of a significant number of studies. Also, much of the information has focused on evaluating impacts in the Strait of Georgia and Puget Sound; there have been no studies in coastal areas or in Alaska. Extrapolating results from Strait or Georgia and Puget Sound to coastal and Alaskan estuaries should be avoided until our information base expands. Because three are environmental and faunal differences between coastal and inland estuaries and between more temperate estuaries and cold climate estuaries, it is also premature to assume that data obtained in one type of estuary necessarily apply in other types.

We also found that impacts in shallow subtidal habitats have been virtually unstudied. Clearly, some major impacts of habitat modifications could occur in subtidal areas since as juvenile salmon grow they become less oriented towards intertidal areas.

SHORTCOMINGS OF THE LITERATURE

The focus in the literature has been almost exclusively on modifications that have negative impacts; we found few investigations of habitat modifications that could benefit salmonid populations. As an example, only three studies describing the effect of wetland creation upon anadromous salmonids were found. Another major data gap is that no studies of impacts to steelhead have been conducted. Although they are found in many of the same watersheds as salmon, there are significant differences in life histories that may make the impacts of some habitat modifications either more or less than for salmon. One of the objectives of our review of each article was to determine if specific biological and physical alterations caused by estuarine modifications were studied and, if so, were impacts found. We found that only a few types of alterations were well studied, namely impacts to morphological features of the habitat, hydrological impacts, and ecological impacts. However, the majority of *direct* alterations have been the subject of a limited number of studies. We believe that this is a major shortcoming of the literature. A careful evaluation of what alterations the modifications cause is vital to an understanding of the impacts on salmonids. Most modifications do not appear to affect salmonids directly but rather they cause some physical or biological alterations, which in turn impact the salmonids. For example, freshwater diversion does not directly impact salmonids in estuaries but rather affects some elements of the ecology of the estuary such as primary production (e.g., by changing salinities), which in turn impacts the salmonid populations.

We identified 10 possible ways that salmonids could respond to alterations caused by estuarine modifications. A major weakness of the existing literature is that most studies have investigated responses that ultimately do not *test* whether the modification impacted the salmonids in terms of their *net* survival. For instance, changes in salmonid abundance or distribution, which were the two most measured response variables, do not necessarily imply that there will be a change in the number of returning adults. The fish may be able to use alternative habitats without an impact to their long-term performance (i.e., survival to reproduction). The ultimate question that studies of impacts of estuarine habitat modifications must try to resolve is: Does the modification affect the long-term performance of the salmonids? Consequently, we suggest that studies assessing the impacts of modifications on salmonids need, if at all possible, to focus on responses that more directly relate to the survival of the animals (i.e., numbers of returning adults). This can be summarized as an alternative question: Does the modification affect the fitness of salmonids? Of the variables we have identified, long- and short-term survival, growth, migration rate, and residence time will reflect whether a modification impacts the number of returning adults. Clearly, studies addressing performance or fitness that encompass whole life histories of the fish are more costly and not possible to conduct in all cases. Thus, we also suggest, that research is needed to determine if changes in distribution and abundance, which are much easier to measure, affect survival.

Generic Problems of Studies

One of the most outstanding features of the literature was that most studies were not very successful at determining whether a modification caused an impact. A number of reasons appear to explain the lack of success in assessing impacts. First, few studies explicitly stated and tested scientific hypotheses. Moreover, although most studies used statistics, we felt that the statistics were either not appropriately used or not an integral part of the analyses of impacts. Second, it was not possible in many studies to establish a clear cause and effect relationship between the response variables and the salmonid populations. In some cases, it was not possible to clearly separate the effects of the modification from other factors, such as natural environmental fluctuations and other habitat alterations. In other cases, the analyses relied on a correlative, retrospective approach that does not establish clear cause and effect.

On the basis of our review of the literature, we note several key elements that need to be included as part of any program assessing relationships between habitat modifications and salmonids. Clearly, a rigorous, scientifically oriented approach that uses statistical techniques (or other quantitative approaches as appropriate) to test *a priori* formulated hypotheses could result in a higher success rate at defining impacts.

Experimental Strategies to Test the Impact of Estuarine Habitat Modifications: A General Method for Development and Testing of a Protocol

A basic strategy is required to test the paradigm that juvenile salmon use of estuarine habitats, both those altered and those restored or created, results in a change in performance or fitness. Given the inherent problem with the intensive, long-term studies required to adequately quantify performance, we propose that a test of fitness associated with estuarine habitat use is the more tractable approach. The foundation of our approach is that higher estuarine growth will result in larger fish which, in turn, translates into higher total survival of the fish that return to spawn as adults. Considerable information exists supporting the linkage between larger fish size and higher survival, and there are some indications that much of the mortality is initiated early in the oceanic phase (e.g., outer estuary and nearshore ocean). In these instances, mortality can be strongly size-selective when the salmon are small. Thus, fish that pass through this period of vulnerability fastest (i.e., by growing rapidly) will have a higher survival. Consequently, relating growth rates to specific patterns of estuarine habitat usage can be used to draw conclusions about survival of the fish. The main focus of this study will be to test the significance of estuarine habitat use to growth rate of juvenile salmon. However, because no study has explicitly tested the presumed relationship between habitat use and growth rate of juvenile salmon and their overall survival, a secondary objective will be to explicitly test the consequences of habitat-specific growth rates to overall survival to adult return.

Ideally, such an experiment should be conducted as a "pure" experiment with all factors under explicit control of the investigator. However, the costs of the habitat modification would typically overdilute the resources available for the scientific evaluation. As an alternative, such a study could utilize the scheduled monitoring of an estuarine habitat mitigation project as a template upon which to base a more intensive *evaluation of access, residence time and growth of juvenile salmon* in modified and unmodified habitats. An important adjunct, however, would be an experiment in which we could estimate the net survival to adulthood of the juveniles that did (versus those that did not) use the natural and modified habitats.

An example of an experimental approach this issue follows:

1. estimate the natural ecology behavior of juvenile salmon in unmodified estuarine habitats relative to physical and biological conditions;
2. estimate the residence time of fish that do reside volitionally in modified and unmodified habitats;
3. estimate the relationship between individual fish residence time and the growth that occurs during the period of residence; and
4. mark fish according to their use of the modified and unmodified habitats such that their survival at return as adults can be estimated reliably.

To determine the preceding objectives, the hypotheses to be tested or designed will evaluate the respective response of fish to modified versus unmodified habitats:

H_{A1}: *There is no difference in the proportion of downstream migrant salmon that use the habitats.*

H_{A2}: *Differences in the proportion of downstream migrant salmon using the habitats cannot be explained by the physical and biological characteristics of the habitats.*

H_B: *There is no difference in the residence time of fish that use the habitats.*

H_C: *There is no difference in daily growth of fish that reside in the habitats.*

H_D: *There is no difference in net survival of adults that use the habitats (to be confirmed in subsequent phases of the study?).*

A methodological approach would be to use coded wire tags (CWTs), otolith marks, and external marking to distinguish different groups of juvenile salmon, and evaluate the distribution of their individual growth rates, on the basis of how they use *at least* three selected estuarine habitats within a given site.

One methodological constraint would be that the habitats would have to be isolated if sampling for juvenile salmon is to have an estimable efficiency. For example, a trap or net would be placed such that each habitat is equally sampled. Ideally, a barrier trap should be used so that no fish can enter or leave the habitat without passing the through the trap.

An important advantage to using certain salmon species and estuaries for this experiment is that hatchery-reared fish can be used as experimental animals in addition to the "wild" fish. While hatchery fish are being held for a short period before the experiment, their otoliths will be marked by placing them in a cold temperature (e.g., >2°C from ambient) bath or by using an elemental mark. Fish could also be marked with an external mark such as fluorescent pigment. Unique marks can be placed on different groups of chinook (approximately 200 per group). Fish from each group would be transported to each habitat and released. The fish will be recaptured in the trap as they volitionally emigrate through the estuary. By examining the otoliths of these fish, growth rates can be estimated from the incremental distances of the daily bands. Fluorescent pigment mark would allow these groups to be distinguished from unmarked fish that passed into the habitats.

Unmarked juvenile salmon that attempted to immigrate to the habitats could also be captured and placed into a chilled-water bath located at the site. This would place a mark or reference point on their otoliths that corresponds to the time they entered the habitat. If the water bath proved infeasible, a method that places an elemental (e.g., trace metal) mark on the otolith could be employed. Subsequently, whenever an unmarked fish emigrated from the habitat, it would be tagged with a CWT. A different tag code could be used to distinguish fish that emigrate from each habitat. Each tag code would thus allow us to estimate the difference in survival between the modified and unmodified. This approach would, however, be critically dependent on the number of migrants that actually exit the habitats. The early growth information on the otoliths will enable the investigator to relate net survival to growth.

Another tag group would also be used as a control. Each group would be uniquely identified in order to distinguish it from the other groups. One group would consist of fish coded-wire-tagged at a trap capturing wild fish from an unmodified upstream site. These fish, identifiable by their external marks, would be excluded from entering the modified and unmodified habitats, and at least one group would be released outside the estuary to assess a "non-estuarine use" treatment. This will allow us to examine the difference between using one or the other of the habitats versus not using these specific or other estuarine habitats.

As indicated in the literature evaluation of Phase I, it will be imperative to incorporate intensive measurements of physical manifestations of the alteration (and of the conditions associated with the natural, unmodified habitat as well) in order to relate the alteration to the response of the biota. At a minimum, hydrology, salinity, temperature, and turbidity and other water quality parameters must be monitored; however, circulation and other physicochemical *processes* also should be identified.

SUMMARY AND RECOMMENDATIONS

We have evaluated the existing literature can be applied to the impact of estuarine habitat modifications on anadromous salmonids and have determined that this literature base does not define the sources or mechanisms of impact. For our purposes, this state of the knowledge does not provide the information needed to develop a protocol for impact assessment because:

1. baseline data are typically lacking,
2. altered habitats are still in a transitional states,
3. alteration-response relationships are not explicitly identified,
4. statistical rigor is generally lacking, and
5. the effect of salmonid response to habitat modification on net survival of the fish has not been identified.

As a consequence, generic, strongly inferential studies have to be designed to resolve these problems. We recommend that a research project that specifically addresses each of these deficiencies be conducted to test the impact of one type of estuarine habitat modification. Although addressing such a minimal component of the potential habitat alterations, such a study should incorporate more than one species of salmonid (e.g., juvenile chum and chinook salmon) and more than one among the spectrum of estuary types (e.g., river valley, fjord). In addition, while testing fish *fitness* will likely be the more economical and efficient approach to this study than testing fish *performance*, we strongly recommend that the study be constructed such that the latter information (i.e., net survival to return as adults) can be obtained by implementing supplemental funding in a later phase.

LITERATURE CITED

Levings, C.D., C.D. McAllister, J.S. MacDonald, T.J. Brown, M.S. Kotyk, and B.A. Kask. 1989. Chinook salmon (*Oncorhynchus tshawytscha*) and estuarine habitat: a transfer experiment can help evaluate estuary dependency. Pages 116-122 *in* C.D. Levings, L.B. Holtby, and M.A. Henderson (eds.), Proceedings, Natl. Workshop Effects of Habitat Alteration Salmonid Stocks. Can. Spec. Publ. Fish. Aquat. Sci. 105. 199 p.

Pritchard, D. W. 1967. What is an estuary: physical viewpoint. Pages 3-5 *in* G.F. Lauff (ed.), Estuaries. Am. Assoc. Adv. Sci., Publ. 83. Washington, D.C.

APPENDIX A. TECHNICAL EXPERTS SURVEYED

LIST OF EXPERTS CONTACTED

BLOMBERG, George
Port of Seattle
P.O. Box 1209
Seattle, WA 98111

BOTTOM, Dan
Oregon Dept. of Fish & Wildlife
Research & Development Section
303 Extension Hall
Oregon State University
Corvallis, OR 97331

CARLETON, James T.
Oregon Institute of Marine Biology
University of Oregon
Charleston, OR 97420

EMMETT, Robert
National Marine Fisheries Service
P.O. Box 155
Hammond, OR

HERREGESSEL, Perry
California Dept. of Fish & Game
4001 North Wilson Way
Stockton, CA 95205

HILLIBY, Bruce
Dept. of Fisheries & Oceanography
1090 West Pender
Vancouver, BC
V6E 2P1 Canada

KJELSON, Marty
U.S. Fish & Wildlife Service
4001 North Wilson Way
Stockton, CA 95205

LANDINGHAM, Joyce
National Marine Fisheries Service
Auk Bay Fisheries Lab
P.O. Box 155
Auk Bay, AK 99821

LEVINGS, Colin
West Vancouver Lab
4160 Marine Drive
West Vancouver, BC
V7V 1N6 Canada

LEVY, David
West Vancouver Lab
4160 Marine Drive
West Vancouver, BC
V7V 1N6 Canada

McINTEE, David
Environmental Planner
Port of Tacoma
P.O. Box 1837
Tacoma, WA 98401

MOYLE, Peter
University of California at Davis
Dept. of Wildlife & Fisheries Biology
Davis, CA 95616

NICHOLAS, Jay
Oregon Dept. of Fish & Wildlife
Research & Development Section
303 Extension Hall
Oregon State University
Corvallis, OR 97331

NORTHCOTE, Thomas
Westwater Research Center
Univ. of British Columbia
Vancouver, BC
V6T 1W5 Canada

PEARCY, William
Oregon State University
School of Oceanography
Corvallis, OR 97331

APPENDIX B. ANNOTATED LITERATURE SEARCH CITATIONS

1. Direct Impacts

Anderson, E.P. 1985. Use by Juvenile Chinook Salmon of Artificial Habitat Constructed from Dredged Material in the Columbia River Estuary. CAN. CONTRACT REPORT HYDROGR. OCEAN SCI., no.20, pp.4-15.

Key Words
logging, estuary, dredging, food sources

Abstract
Numerous potentially conflicting commercial, recreational, and wildlife users compete for the resources of the relatively small Campbell River estuary. Two of the largest users are the logging industry and juvenile salmon on their downstream migration (wild juvenile chinook salmon as well as chinook and coho from the Quinsam hatchery). In order to improve the efficiency of log handling and to relieve resource-use conflicts, British Columbia Forest Products dredged a new logpond at the southwestern periphery of the estuary. In cooperation with the Dept. of Fisheries and Oceans, BCFP rehabilitated the old booming ground and constructed four experimental islands with shorelines which included experimental features such as coves and narrow grooves. The islands were built from materials dredged from the new logpond, which otherwise would have been dumped at sea. They were planted with plugs of sedge or rush salvaged from the dredged area. Construction and planting were completed in February 1982. The purpose of this study was to determine the stage of development of animal communities on the islands, to assess the use of the islands by fish (in particular relative use by wild and hatchery salmon) and to evaluate the island communities as food sources for juvenile salmon.

Anderson, E.P.; Birtwell, I.K.; Beyers, S.C.; Hincks, A.V.; O'Connell, G.W. 1981. Environmental Effects of Harbor Construction Activities at Steveston, British Columbia. Part 1. Main Report. Canadian Technical Report Fisheries and Aquatic Sciences, no. 1070, 160 pp.

Key Words
environmental impacts, harbor construction, water quality, benthos

Abstract
From January to December 1979, the authors sampled the estuarine biota and environment at the Steveston Harbor, near the mouth of the Fraser River, in order to assess the effects of harbor development. No unacceptable levels of heavy metal or organic pollutants were found. During the periods of intensive fish processing, harbor waters showed elevated concentrations of ammonia and phosphate. Dissolved oxygen was somewhat depressed in the near-bottom water at the landward end of the harbor. The subtidal benthos was divisible into three community types, corresponding to deep silt, shallow silt, and sand habitats. The deep silt community repopulated a small dredged area within one month after dredging stopped. Juvenile chum salmon (O. keta) were clearly more abundant than chinook near the marsh habitat than near sand. One common effect of harbor dredging is to replace marsh with sand.

Brownlee, M.J.; Mattice, E.R.; Levings, C.D. 1984. The Campbell River Estuary: A Report on the Design, Construction and Preliminary Follow-up Study Findings of Intertidal Marsh Islands Created for the Purposes of Estuarine Rehabilitation. Canadian Manuscript Report Fisheries and Aquatic Science, no. 1789, 63 pp..

Key Words
habitat improvement

Abstract

This report focuses on the cooperative efforts of agency staff, members of industry and the public in developing and constructing a new log-handling facility and rehabilitating an industrialized estuarine area of approximately 32 hectares that had been intensively utilized for log handling activities for over 75 years. Preliminary follow-up study results indicate that the intertidal islands are stable, 93% of the 23,302 marsh cores transplanted are growing, invertebrate colonization is still incomplete, juvenile wild chinook (O. tshawytscha) and chum (O. keta) salmon utilize the islands and catches are proportional to the abundance of salmon fry in the estuary. Hatchery reared juvenile salmon do not make extensive use of the islands. Migratory bird use of the islands has been recorded.

Cardwell, R.D.; Olsen, S.J.; Carr, M.I.; Sanborn, E.W. 1980. Biotic, Water Quality and Hydrologic Characteristics of Skyline Marina in 1978. Washington Department of Fisheries, Technical Report No. 54.

Key Words
environmental characteristics, fish populations

Abstract

Fish, zooplankton, and water quality characteristics of Skyline Marina in north Puget Sound were compared to the marina's source water in monthly surveys conducted from March to October 1978. A companion study defined the marina's flushing properties. Fish were indexed mainly by purse seining and the food habitats of seven species of juvenile salmon (Oncorhynchus spp.)and baitfish examined in terms of ontogenic-seasonal variation. Symbol surface zooplankton larger than 505 um were indexed with push nets. Water quality was described through measurements of general parameters (e.g., temperature, phytoplankton, nutrients), heavy metal and organic concentrations in sediments, heavy metal residues in adult Pacific oysters (Crassostrea gigas), and acute toxicity of ambient waters to Pacific oyster larvae.

Dutta, L.K.; Sookachoff, P. 1975. A Review of Suction Dredging Monitoring in the Lower Fraser River, 1971-1975. Fisheries and Marine Service Canada, Technical Report Series No. PAC/T-75-27.

Key Words
suction dredging, fry, mortality rate

Abstract

The Fraser River is used as a migratory route by chum, coho, sockeye, and pink salmon. Each spring, salmon fry utilize the Fraser River during their downstream migration. Estimated 6.25 billion eulachon larvae; 413 million chum, pink and chinook salmon fry, 1 million steelhead, 1.6 million chinook, 2.1 million coho, and 45 million sockeye juveniles travelled through the lower Fraser River during the period March 15 to May 31, 1974. Peak daily totals of 10.4 million chum fry and 9.6 million pink fry occurred on May 1st, 1974 and April 5, 1974, respectively. The lower 25 miles of the river from the mouth to the trifurcation walls is becoming increasingly utilized for navigation and sand-borrow purposes. Associated suction dredging activities carried out during the downstream fry migration period, viz March 15th to May 31st, have been the cause of serious concern for the fisheries resource managers. Since 1971 the Fisheries and Marine Service has been actively involved in assessing the impact of the anchored suction pipeline as well as the mobile hopper suction dredges on the salmon fisheries resources of the lower Fraser River. Monitoring techniques have evolved from the initial partial dip net screening to the present 100% screening of the spoil runoff.

**Kjelson, M.A.; Brandes, P.L. 1989. The Use of Smolt Survival Estimates to Quantify the Effects of Habitat Changes on Salmonid Stocks in the Sacramento-San Joaquin Rivers, California. Proceedings of the National Workshop of Effects of Habitat Alteration on Salmonid Stocks, Canadian Special Publication of Fisheries and Aquatic Sciences 105. Edited by C.D. Levings, L.B. Holtby, and M.A. Henderson.

Key Words

mark-recapture studies, smolts, chinook

Abstract

Mark-recapture studies of smolt survival in the Sacramento-San Joaquin Delta of California provides empirical data on the effects of water development on fall-run chinook salmon. Recoveries of coded-wire tagged hatchery fish from the ocean troll fishery and estuarine trawling yielded two survival measures that were positively correlated (r=0.90). Smolt survival from both measures were highly correlated to river flow, temperature, and percent diversion. Survival of fish exposed to diversion was about 50% less than those not exposed. Study designs to quantify the independent effects of temperature on survival and the survival of wild smolts are presented. Survival results are being used to evaluate estuarine flow standards governing state and federal water project operations and other salmon protective measures. Regressions of survival and flow applied to simulated historical flows at varied levels of water development indicated estuarine survival has decreased a minimum of 30% in the last 70 years. Spawner escapements in the Central Valley are positively correlated to flow during their spring smolt outmigration, suggesting that flow alterations in upstream and estuarine habitats at that time influence adult stock production.

Kjelson, M.A.; Raquel, P.F.; Fisher, F.W. 1981. Influences of Freshwater Inflow on Chinook Salmon (Oncorhynchus tshawytscha) in the Sacramento-San Joaquin Estuary. Proceedings of the National Symposium on Freshwater Inflows to Estuaries, San Antonio TX, Sept. 9-11, 1980. Fish & Wildlife Service, Office of Biological Services Report, FWS/OBS-81/04, Vol. II, pp. 88-108.

Key Words
survival, freshwater inflow, chinook

Abstract
This paper describes present knowledge regarding the influence of freshwater inflow on the survival, abundance, migration and rearing of chinook salmon in the upstream portion of the Sacramento-San Joaquin Estuary. Preliminary results indicate that additional inflow at the appropriate time will increase the numbers of fry and juvenile salmon using the estuary and the survival of juveniles in the estuary. Results are based on seine and trawl surveys, salmon collections at water diversion fish screens, and mark-recapture techniques. Flow related concerns for salmon in the estuary stem from (1) water development activities that have altered the distribution of flow resulting in impacts on young and adult migration, and (2) the lack of comprehensive flow standards with which to protect salmon. Future efforts to better quantify salmon flow needs include long-term seine and trawl surveys in both the upper and lower portions of the estuary, as well as intensive, replicated marking experiments done under varied conditions and supported by estuarine, ocean and inland recovery programs.

Levings, C.D. 1985. Juvenile Salmonid Use of Habitats Altered by a Coal Port in the Fraser River Estuary, British Columbia. Marine Pollution Bulletin, vol. 16, no. 6, pp. 248-254.

Key Words
impacts, recolonization, juveniles

Abstract
Juvenile chinook, chum, and pink salmon used habitats modified by a coal port at the Fraser estuary in southwestern British Columbia. Recent construction for expansion of the port has obliterated feeding areas, invertebrate communities, and possibly herring habitat from the local production system. Further studies are required to document recolonization of disrupted habitats and to investigate if present food webs are similar to those before construction. Juvenile salmon may be diverted by causeways and terminals and this also requires study.

Levy, D.A.; Northcote, T.G.; Barr, R.M. 1982. Effects of Estuarine Log Storage on Juvenile Salmon. Westwater Research Center Technical Report, no. 26, 120 pp..

Key Words
environmental impacts, forest industry, juvenile

Abstract
Fish populations within marsh tidal channels of the North Arm, the Middle Arm, and the Main Arm of the Fraser River estuary were monitored between March and June of 1980. Highest catches of juvenile salmon were obtained from the Main Arm site on most dates. Catch results suggested similar fish population densities in the three North Arm sites, one of which was located in the Point Grey log storage area. Current velocities measured adjacent to the fish traps during May of 1981, and calculations of water flow discharge volumes, confirmed that the number of juvenile salmon per m^3 was similar to tidal channels of the log storage area and the neighboring Musqueam Marsh. Comparison of the size characteristics of chinook fry captured in the two areas indicated relatively good growth conditions for this species in the Point Grey log storage area.

**Levy, D.A.; Northcote, T.G.; Hall, K.J.; Yesaki, I. 1989. Juvenile Salmonid Responses to Log Storage in Littoral Habitats of the Fraser River Estuary and Babine Lake. Proceeding of the National Workshop on Effects of Habitat Alteration on Salmonid Stocks. Canadian Special Publication of Fisheries and Aquatic Sciences 105, Edited by C.D. Levings, L.B. Holtby, and M.A. Henderson.

Key Words
log storage, littoral habitats, juveniles

Abstract
Juvenile salmon often pass through and reside in littoral habitats of estuaries and lakes on their downstream migration to the Pacific Ocean. These migrants can be exposed to stored log booms and log-related habitat modifications. Effects of log storage on juvenile salmon were evaluated in two contrasting littoral storage areas. In the Fraser River estuary, juvenile chinook and chum salmon densities were similar in an area utilized for log storage and in an adjacent marsh. Epibenthic invertebrates were abundant throughout the storage area. In Babine Lake, juvenile sockeye were not observed in a recently-developed log transportation facility that became severely hypoxic during the vernal warming period. Deoxygenation was the result of an elevated biochemical oxygen demand produced by a microbial gelatinous slime layer which coated the underside of logs. Benthic insect larvae in the storage area were drastically reduced by the deposition of gelatinous slime material and wood debris. The contrasting results from the two studies probably reflected differences in water exchange processes in the log storage sites. Where water circulation is restricted, severe degradation of water quality may influence the littoral distribution of juvenile salmon.

Martin, D.J.; Salo, E.O.; Snyder, B.P. 1977. Field Bioassay Studies on the Tolerances of Juvenile Salmonids to Various Levels of Suspended Solids. University of Washington, Fisheries Research Institute, FRI-UW-7713.

Key Words
bioassays, dredging, avoidance behavior

Abstract
Information on the impacts of dredging operations on the behavior and survival of juvenile salmonids, especially in the marine environment, is limited. Much of the research to date deals with the toxic effects of suspended sediment on non-salmonids and benthic invertebrates. No information was found on the effects of suspended sediment on the behavior of salmonids in saltwater. Therefore, the objectives of this research were to determine the lethal levels of suspended sediments on juvenile chum salmon and, secondarily, to determine if juvenile chum salmon would avoid suspended sediment.

Pickard, A.; Baraco, A.; Kano, R. 1982. Occurrence, Abundance, and Size of Fish at the Roaring River Slough Intake, Suisin Marsh, California, During the 1980-81 and 1981-82 Diversion Seasons. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary, Technical Report No. 3, FF/BIO-4ATR/82-83.

Key Words
channel modifications, diversion facilities, intake culverts, fish screens

Abstract
A sampling program at the intake for the Roaring River Slough distribution system in the Suisin Marsh was carried out from November, 1980 through May, 1981 and from September, 1981 through March, 1982. Over 14,00 fish of 34 species were collected, nearly all of which were less than 150 mm (6 in.) in length. The most numerous species was the delta smelt followed by the threespine stickleback, longfin smelt, and chinook salmon. A list of common and scientific names of fish collected is provided in the Appendix.

Prinslow, T.E.; Whitmus, C.J.; Dawson, J.J.; Bax, N.J.; Snyder, B.P.; Salo, E.O. 1980. Effects of Wharf Lighting on Outmigrating Salmon, 1979. Fisheries Research Institute, University of Washington, FRI-UW-8007.

Key Words
wharf lighting, outmigration, chum salmon

Abstract
During 1976-1978 and 1979, the Fisheries Research Institute of the University of Washington conducted a series of experiments to assess the effects of wharf lighting at the U.S. Naval Submarine Base-Bangor on outmigrating juvenile salmon in Hood Canal, Washington. Chum are the principal salmonid in Hood Canal, and pink the second most abundant. Previous studies reported that light may attract or repulse juvenile salmon depending on its quality (type and wavelength) and intensity. This report presents the results of the 1979 experiments and reviews those conducted during 1976 and 1978.

Ratté, Lawrence D. 1985. Under-Pier Ecology of Juvenile Pacific Salmon in Commencement Bay, Washington. University of Washington, Masters Thesis

Key Words
under pier habitat, artificial lighting, outmigration

Abstract
Studies of the behavior of juvenile salmonids were conducted in 1984 and 1985 at the Port of Tacoma, Washington in response to concerns about the reductions in natural light under piers. Artificial lights were installed under the pier at Terminal 4 to test whether they would enhance the under-pier habitat for juvenile salmon. During the spring outmigration period, the traps were sampled with ships present and absent alongside the pier, and during flood and ebb tides. Measurements of light intensity showed that light levels were reduced under the pier by roughly 2-4 orders of magnitude, but were sufficient to facilitate feeding and schooling of juvenile salmon, except when ships were present and light were off.

Rosberg, G.E.; Greer, G.L. 1985. Migration Rate and Behavior of Adult Sockeye and Chum Salmon Through Trained and Untrained Sections of the Lower Fraser River. Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1349.

Key Words
adults, sockeye, chum, migration, behavior, training walls, radio telemetry, hydroacoustic monitoring

Abstract
Migrating adult sockeye and chum salmon were captured in the lower reaches of the Fraser River and fitted internally with radio-telemetry tags. The migration speeds of the released fish were determined over tracks ranging from approximately 3-19 km in the area between Sandheads and New Westminster. Mean absolute ground speed for sockeye and chum was similar, but mean speed relative to body length was greater for sockeye because of their smaller size. For both species, migration speed was greater through the trained sections of the river than the untrained sections. Radio-tagged salmon released in the slack water behind training walls returned via the downstream end to the main channel, and resumed upstream migration, in times ranging from immediate to 10.5 hours. Hydroacoustic monitoring of river transects indicated no significant effect of tide or vertical and horizontal distribution of salmon-sized targets in a lower, untrained reach of the river. Larger numbers of targets were recorded in a trained section on ebb tides with some indication of a significant horizontal distribution and interaction between these two factors. Hydroacoustic monitoring of a fish passage opening at the upstream end of a training wall showed that some salmon also return to the main channel via this route (in larger numbers on the ebb tide). Results of the present study suggest that existing training structures in the lower Fraser mainstream do not seriously impede the adult salmon migration.

Ryall, P.; Levings, C.D. 1987. Juvenile Salmon Utilization of Rejuvenated Tidal Channels in the Squamish Estuary, British Columbia. Canadian Manuscript Report Fisheries and Aquatic Sciences, no. 1904, 26 pp..

Key Words
habitat improvement, fish culture

Abstract
In 1984, a 600 m long channel was excavated through disrupted habitat at the Squamish River estuary in order to reconnect natural tidal channels blocked by port construction. Tidal access was increased about 87% during spring tides. Juvenile coho (Oncorhynchus kisutch) and chum (O. keta) and a variety of non-salmonids used the channel and reconstructed habitat. Catches of coho in beach seines were comparable to or greater than those at reference habitats. Residence time of coho introduced to the restored area was about 10 days and 3 days in the middle and end of outmigration, respectively. Coho fry from the reconstructed channels fed on adult insects and stomach contents as a percent of body weight were similar to natural sites. Chum fry catches and residency estimates at the reconnected channels were also comparable to or greater than those at reference habitats.

**Salo, E.O.; Bax, N.J.; Prinslow, T.E.; Whitmus, C.J.; Snyder, B.P.; Simenstad, C.A. 1980. The Effects of Construction of Naval Facilities on the Outmigration of Juvenile Salmonids from Hood Canal. University of Washington, Fisheries Research Institute, Final Report, FRI UW-8006, 159 pp.

Key Words
outmigration, shoreline construction, offshore piers

Abstract

One of four studies conducted when the U.S. Navy expanded its facilities on Hood Canal, the Outmigration Study examined five seasons of outmigration using beach seines and townet surveys to measure abundance and migration pathways of juvenile salmonids. Chum salmon, the abundant species - and one of the more sensitive to environmental changes in nearshore environs- varied in abundance from year to year. The variations among the years were not related to the numbers released annually from hatcheries, although within any year the variation in abundance was closely related to hatchery releases. This suggests large but differing early marine mortality rates from year to year. Migration routes were defined and comparisons were made of the numbers migrating on the west shore and on the east shore where the support base was located. There is indication that the juvenile chum move offshore around wharves as they migrate north out of the canal. Although evidence is circumstantial, changes in migratory patterns and reduction in catch appear to be related to the construction and operation of the piers. Without a more extensive database with which to quantify increases in natural mortality rates due to natural environmental fluctuations, the authors remain uncertain as to the significance of the perturbations.

Salo, Ernest O.; Prinslow, Thomas E.; Campbell, Robert A.; Smith, David W.; Snyder, Bruce P. 1979. Trident Dredging Study: The Effects of Dredging at the U.S. Naval Submarine Base at Bangor on Outmigrating Juvenile Chum Salmon, Oncorhynchus Keta, in Hood Canal, Washington. University of Washington, Fisheries Research Institute, FRI-UW-7918.

Key Words
dredging, drydock construction, bioassays

Abstract

Between February and July 1977, approximately 224,000 cubic yards of bottom sediments were dredged from Hood Canal, removing two layers of sediment, recent alluvium (overburden) and glacial till, for construction of a gravity drydock at the U.S. Naval Submarine Base, Bangor, Washington. The sediment load of the plume created by the dredging was limited, by the Washington Department of Fisheries (WDF), to no more than 30 mg/liter over ambient. The levels were monitored weekly and daily by WDF and U.S. Navy Department of Ecology respectively. As part of the cooperative monitoring program, the Fisheries Research Institute monitored the impact of dredging using juvenile chum salmon as test animals in static, flow-through and field bioassays. The University of Washington R/V KUMTUKS was moored 500 m north of the dredge site and was used for the static and flow-through bioassays, as well as the base of field operations.

Salo, Matthew E.; Salo, Ernest O.; Snyder, Bruce P. 1977. A Preliminary Study of the Effects of Pier Lighting on Fishes. University of Washington, Fisheries Research Institute, FRI-UW-7712.

Key Words
docking facilities, piers, lighting

Abstract
Seven large docking facilities are planned for the 4 miles of shoreline of Hood Canal in the U.S. Navy's Bangor Annex near Keyport, Washington. These concrete piers will extend up to 400 m from shore and will cover or enclose approximately 30 hectares of water. The proposed lighting will provide constant illumination underneath and outside the piers. From February to July, the major portion of chum salmon outmigrant populations from Hood Canal spawning grounds pass along this shoreline. The effects of the proposed lighting on these migrants, resident fishes, and other salmonids is unknown. This study was carried out in July 1976 to determine if lighting similar to that proposed would attract and hold fish. Further work investigated the effect of different colors of light on fish. Feasibility of identification and enumeration of fishes present in the experimental area was investigated.

Shreffler, D.K.; Simenstad, C.A.; Thom, R.M.; Cordell, J.R.; Salo, E.O. 1988. Juvenile Salmon Foraging in a Restored Wetland. Proceedings: First Annual Meeting on Puget Sound Research. March 18-19, 1988, Seattle, WA. Published by the Puget Sound Water Quality Authority, Seattle, WA.

Key Words
mitigation, juveniles, feeding habits

Abstract
A 9.6 acre wetland system was constructed in 1985-86 in the Puyallup River estuary to mitigate the filling of a proximal, similarly sized wetland. The Lincoln Avenue wetland system is a habitat mosaic of tidal channels, mudflats, a sedge marsh, a cattail marsh, a swamp, riparian hardwoods, and a grassland. Monitoring since 1986 has shown that the wetland system is utilized in the spring by outmigrating juvenile salmon. Chironomid insects (midge larvae, pupae, and adults) were the dominant prey in chum salmon and chinook salmon stomachs. There was essentially no overlap between epibenthic prey potentially available and prey consumed. Continued monitoring of the restored wetland will not only increase our understanding of the functional value of such wetlands to juvenile salmon, but should also have significant bearing on the design and monitoring of future mitigation of this type. Comparable data from a "natural" wetland in southern Puget Sound would be invaluable in assessing the success or failure of the restoration project but is not available in the foreseeable future.

Stevens, D.E.; Miller, L.W. 1983. Effects of River Flow on Abundance of Young Chinook Salmon, American Shad, Longfin Smelt, and Delta Smelt in the Sacramento-San Joaquin River System. North American Journal of Fisheries Management, 3:425-437, 1983.

Key Words
abundance indices, dispersal, spawning periods, nursery periods

Abstract
Annual abundance indices for young fall-run chinook salmon, American shad, and longfin smelt increased directly with river flow rates during the spawning and nursery periods. Annual abundance of young delta smelt did not vary with river flow. Several factors associated with flow could explain the relationships described for chinook salmon, American shad, and longfin smelt. The one factor common to all affected species was that dispersal of young increases when flows increase, which probably results in decreased density-dependent mortality.

Tutty, B.D.; Raymond, B.A.; Conlin, K. 1983. Estuarine Restoration and Salmonid Utilization of a Previously Dyked Slough in the Englishman River Estuary, Vancouver Island, British Columbia. Canadian Manuscript Report Fisheries and Aquatic Science, no. 1689, 58 pp.

Key Words
salmonid, rearing, estuary, enhancement, benthos

Abstract
Tidal inundation of the northern portion of the Englishman River estuary ceased as the result of the construction of a sea dyke in 1969. This dyke was breached on March 27, 1979. Reactivation of 87 acres of slough was expected to provide significant estuarine rearing area for salmonids and other fish species. A series of fish trappings and benthic surveys was undertaken in 1979 to assess whether salmonids did utilize the reactivated estuary. Significant numbers of rearing chum moved into the slough and were captured during the April and May period. Their stomach contents appeared most representative of the epibenthos found there. A significant feature of the study was that chum fry appeared to rear longer and grow larger in the slough than in the adjacent estuary. Adult chum salmon have been observed spawning in groundwater upwelling areas in the upper portion of the reactivated slough. These factors indicate that with further study this estuarine restoration technique may be a valuable enhancement tool.

Westley, Ronald E.; Finn, Earl; Carr, Mark I.; Tarr, Marvin A.; Scholz, Albert J.; Goodwin, Lynn; Sternberg, R.W.; Collias, E.E. 1975. Evaluation of Effects of Channel Maintenance Dredging and Disposal on the Marine Environment in Southern Puget Sound, Washington. Washington Department of Fisheries, Technical Report #15.

Key Words
dredging, toxicity, environmental impacts

Abstract
This report represents the results of a study conducted by the Washington State Department of Fisheries for the Seattle District of the U.S. Army Corps of Engineers to gather additional information on the problem and the effects of harbor and channel dredging on the marine environment. The objective of this study was to aid in finding methods of avoiding or minimizing possible damage.

2. INDIRECT IMPACTS

Corps of Engineers, Seattle District, Seattle WA. 1984. Feasibility Study for Habitat Development Using Dredged Material at Jetty Island, Everett, WA; Final Report. NTIS #AD -A146 512/9/HDM.

Key Words
dredge disposal, Puget Sound, islands, modification

Herrgesell, P.L.; Kohlhorst, D.W.; Miller, L.W.; Stevens, D.E. 1981. Effects of Freshwater Flow on Fishery Resources in the Sacramento-San Joaquin Estuary. NTIS #PB82-131434, Proceedings of the National Symposium on Freshwater Inflow to Estuaries, San Antonio, TX. Sept. 9-11, 1980. Fish and Wildlife Service, Office of Biological Services report FWS/OBS-81/04, Vol. II, p. 71-87.

Key Words
water development, salinity intrusion

Kaplan. E.H.; Welker. J.R.; Kraus, M.G. 1974. Some Effects of Dredging on Populations of Macrobenthic Organisms. Fishery Bulletin, 72: 2.

Key Words
macrobenthic organisms, productivity, dredging

Levings, C.D. 1974. River Diversion and Intertidal Benthos at the Squamish River Delta, British Columbia. Fresh Water on the Sea. Proceedings from a Symposium on the Influence of Fresh Water Outflow on Biological Processes in Fjords and Coastal Waters, 22-25 April, 1974, Geilo, Norway. Editors: Skreslet, S.; Leinebo, R.; Matthews, J.; and Sakshaug, E.

Key Words
river diversion, industrial development, training wall, fjord

Levings, C.D. 1980. Consequences of Training Walls and Jetties for Aquatic Habitats at Two British Columbia Estuaries. Coastal Engineering, 4: 111-136.

Key Words
training walls, channelization, salt wedge, erosion

Levings, C.D. 1982. The Ecological Consequences of Dredging and Dredge Spoil Disposal in Canadian Waters. National Research Council of Canada, Publication No.18130.

Key Words
dredging, ecosystem management, dredge spoil disposal, ecological impacts

Levings, C.D.; McDaniel, N.G. 1976. Industrial Disruption of Invertebrate Communities on Beaches in Howe Sound, B.C. Canadian Fisheries and Marine Service Technical Report, #663, 105pp.

Key Words
industrial disruption, invertebrates, distribution

Levings, C.D.; Moody, A.I. 1976. Studies of Intertidal Vascular Plants, Especially Sedge, on the Disrupted Squamish River Delta, British Columbia. Canada Fisheries and Marine Service Technical Report #606, 56 pp..

Key Words
industrial disruption, primary production, turbidity

Mitchell, D.L. 1981. Salt Marsh Re-Establishment After Dike Removal in the Salmon River Estuary, Lincoln County, Oregon. Estuaries, vol. 4, no. 3, p. 261.

Key Words
dike, salt marsh, subsidence, salt water flooding

O'Neal, G; Sceva, J. 1971. Effects of Dredging on Water Quality in the Northwest United States. Environmental Protection Agency, Region X, Seattle, WA. 158 p.

Key Words
dredging, dredge disposal, environmental impacts

Parametrix, Inc. 1985. Sand/Gravel/Riprap Colonization Study. Final Report to the Port of Seattle, Document No. 85-0614-013F.

Key Words
riprap, mitigation, epibenthic organisms

Stanhope, M.J.; Levings, C.D. 1985. Growth and Production of Eogammarus Confervicolus (Amphipoda: Anisogammaridae) at the Log Storage Site and in Areas of Undisturbed Habitat Within the Squamish Estuary, British Columbia. Canadian Journal Fisheries and Aquatic Sciences, vol. 42, no. 11, pp. 1733-1740.

Key Words
pollution indicators, growth, biological production

3. BACKGROUND (NON-INCLUSIVE)

Allen, M.A.; Hassler, T.J. 1984. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest) - Chinook Salmon, Report No. Biological-82(11.49) Fish and Wildlife Service, Washington, DC. Division of Biological Services; WES, Vicksburg, MS. NTIS #PB86-235439/HDM

Key Words
profiles, habitat, life cycles, environmental impacts

Cannon, Thomas C. 1982. The Importance of the Sacramento-San Joaquin Estuary as a Nursery Area of Young Chinook Salmon, Striped Bass and Other Fishes. Envirosphere Company, Newport Beach, California for the U.S. Department of Commerce, NMFS, Southwest Region.

Key Words
estuarine dependence, spawning grounds

Cardwell, Rick D.; Koons, Robert R. 1981. Biological Considerations for the Siting and Design of Marinas and Affiliated Structures in Puget Sound. Washington Department of Fisheries, Technical Report No. 60.

Key Words
marinas, bulkheads, biological impacts

Hassler, T.J. 1982. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest). Coho Slamon; Biological Report. California Cooperative Fishery Research Unit, Arcata, CA. Report No. FWS-82/11.70; WES/TR/EL-82-4.70. NTIS #AD-A190 950/6/HDM.

Key Words
habitats, salmon, wildlife, life cycles, barriers

Healey, M.C. 1979. Utilization of the Naniamo River Estuary by Juvenile Chinook Salmon, *Oncorhynchus tshawytscha*. Fishery Bulletin, 77(3), 653-668.

Key Words
downstream migration, growth rates

Healey, M.C. 1982. Juvenile Pacific Salmon in Estuaries: The Life Support System. Estuarine Comparisons, Victor S. Kennedy (ed.). New York: Academic Press. 1982.

Key Words
feeding requirements, productivity

Isakson, J.S.; Houghton, J.P.; Rogers, D.E.; Parker, S.S. 1985. Fish Use of Inshore Habitats North of the Alaska Peninsula, June-September 1984 and June-July 1985; Final report, National Ocean Service, Anchorage, AK, Ocean Assessments Division. Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office. NTIS #PB88-244652/HDM.

Key Words
water pollution, salmon, field tests

Kask, B.A.; Brown, T.J.; McAllister, C.D. 1986. Nearshore Epibenthos of the Campbell River Estuary and Discovery passage, 1982, in relation to Juvenile Chinook Diets. Canadian Technical Report Fisheries and Aquatic Science, no. 1449, 59 pp..

Key Words
food organisms, feeding behavior

Kehoe, D.M. 1983. The Effects of Grays Harbor Estuary Sediment on the Osmoregulatory Ability of Coho Salmon Smolts, Oncorhynchus kisutch. Bulletin of Environmental Toxicology, 30: 522-529.

Key Words
dredging, sediments, impacts

Kjelson, M.A.; Raquel, P.F. 1981. The Life History of Fall Run Juvenile Chinook Salmon, Oncorhynchus tshawytscha, in the Sacramento-San Joaquin Estuary of California. Estuaries, vol.4, no.3, p.285.

Key Words
oncorhynchus tshawytscha; life history; growth; migrations; diets; Sacramento-San Joaquin estuary

Kotyk, M.S.; Brown, T.J.; Kask, B.A.; Levings, C.D.; McAllister, C.D.; MacDonald, J.S.; Chang, B.D. 1985. Length and Weight Data for Unmarked Juvenile Salmonids Sampled in the Campbell River Estuary and Discovery Passage. Canadian Data Report Fisheries and Aquatic Science, no. 513, 57 pp..

Key Words
fish catch statistics

LeGore, Richard S.; DesVoigne, D.M. 1973. Absence of Acute Effects on Threespine Sticklebacks (*Gasterosteus aculeatus*) and Coho Salmon (*Oncorhynchus kisutch*) Exposed to Resuspended Harbor Sediment Contaminants. Journal Fisheries Research Board of Canada, vol. 30, No. 8, pp. 1240-1242.

Key Words
dreding, bioassay, coho, contaminants

Levings, C.D.; McAllister, C.D.; Change, B.D. 1986. Differential Use of the Campbell River Estuary, British Columbia, by Wild and Hatchery-Reared Juvenile Chinook Salmon. Canadian Journal Fisheries and Aquatic Science, vol. 43, no.7, pp. 1386-1397.

Key Words
migrations, nursery grounds

Levy, D.A., Northcote, T.G. 1982. Juvenile Salmon Residency in the Marsh Area of the Fraser River Estuary. Canadian Journal of Fisheries and Aquatic Sciences, 39: 2, pp. 270-276.

Key Words
chinook, chum, pink, juvenile residency, marsh tidal channel, Fraser Estuary, estuary growth

Levy, D.A.; Levings, C.D. 1978. A Description of the Fish Community of the Squamish River Estuary, British Columbia: Relative Abundance, Seasonal Changes, and Feeding Habitats of Salmonids. Canadian Fisheries and Marine Service Manuscript Report No. 1475.

Key Words
estuaries, juveniles, growth, biological surveys

Levy, D.A.; Northcote, T.G. 1983. Fish Utilization of Fraser Estuary Marshes. Estuaries, vol. 4, no. 3, p. 263.

Key Words
wetlands, nursery grounds

Levy, D.A.; Northcote, T.G.; Birch, G.J. 1979. Juvenile Salmon Utilization of Tidal Channels in the Fraser River Estuary, British Columbia. Westwater Research Center Technical Report No. 23, 81 pp..

Key Words
tidal channels, juveniles, residency time, distribution, feeding habits

Lipovsky, S.J., Columbia Science, 1985. 1985. Port of Seattle Terminal 91: Habitat Mitigation Monitoring Study. Columbia Science, Seattle, WA. Prepared for Port of Seattle.

Key Words
riprap, mitigation, habitat, outmigration

MacDonald, J.S.; Birtwell, I.K.; Kruzyski, G.M. 1987. Food and Habitat Utilization by Juvenile Salmonids in the Campbell River Estuary. Canadian Journal of Fisheries and Aquatic Sciences, vol. 44, no. 6, pp. 1233-1246.

Key Words
feeding behavior, juveniles

Mortensen, Donald G.; Snyder, Bruce P.; Salo, Ernest O. 1976. An Analysis of the Literature on the Effects of Dredging on Juvenile Salmonids. Fisheries Research Institute, University of Washington, FRI-UW-7605.

Key Words
dredging, juveniles, suspended solids

Pearce, T.A.; Meyer, J.H.; Boomer, R.S. 1982. Distribution and Food Habitats of Juvenile Salmon in the Nisqually Estuary, Washington, 1979-1980. Fisheries Assistance Office, US Fish & Wildlife Service, Olympia WA.

Key Words
distribution, food habits, juveniles, outmigration

Raymond, B.A.; Wayne, M.M.; Morrison, J.A. 1985. Vegetation, Invertebrate Distribution and Fish Utilization of the Campbell River Estuary, British Columbia. Canadian Manuscript Report of Fisheries and Aquatic Sciences, no. 1829, 50 pp..

Key Words
environmental survey, aquatic plants

Sibert, J.R. 1979. Detritus and Juvenile Salmon Production in the Naniamo Estuary: 2. Meiofauna Available as Food to Juvenile Chum Salmon (Oncorhynchus keta). Journal of Fisheries Research Board Canada, 36(5): 497-503.

Key Words
harpacticoid copepods, secondary production, detritus, turnover ratios, meiofauna

Simenstad, C.A.; Fresh, K.L.; Salo, E.O. 1982. The Role of Puget Sound and Washington Coastal Estuaries in the Life History of Pacific Salmon: An Unappreciated Function. Estuarine Comparisons, Victor S. Kennedy (ed.). New York: Academic Press. 1982.

Key Words
residence time, estuarine utilization

Slotta, L.S.; Hancock, D.R.; McCauley, J.E.; Sollitt, C.K.; Sander, J.M.; Williamson, K.J. 1974. An Examination of Some Physical and Biological Impacts of Dredging in Estuaries. Interim Progress Report to the Division of Environmental Systems and Resources. Interdisciplinary Studies of the Schools of Engineering and Oceanography, Oregon State University. 257 p.

Key Words
dredging, biological impacts, physical impacts

Slotta, L.S.; Sollitt, C.K.; Bella, D.A.; Hancock, D.H.; McCauley, J.E.; Parr, R. 1973. Effects of Hopper Dredging and in Channel Spoiling in Coos Bay, Oregon. Interdisciplinary Studies of the School of Engineering and School of Oceanography, Oregon State University, 133 p.

Key Words
dredging, dredge disposal, environmental impacts

Tutty, B.D. 1976. Assessment of Techniques Used to Quantify Salmon Smolt Entrainment by a Hydraulic Suction Hopper Dredge in the Fraser River Estuary. Fisheries and Marine Service Canada, Technical Report Series No. PAC/T-76-16.

Key Words
dredging, mortality rate

VTN Environmental Sciences 1982. 1982 Distribution, Abundance and Food Habitats of Juvenile Salmon at the Heads of Wilson Arm/Smeaton Bay and Boca de Quadra. Prepared for the United States Borax and Chemical Corporation on Behalf of the Pacific Coast Molybdenum Company.

Key Words
estuaries, salmon, outmigration_

APPENDIX C. LITERATURE CATEGORIZATION FORM

The majority of this evaluation format is self explanatory. Parts I and II (General Study Information and Descriptive Characteristics) provide background, species identification, and habitat classification. The primary focus of the General Study Information section was to place the study within some context of scientific rigor, peer-review and scope. The objective of the Descriptive Characteristics section was to define the regional and biological scope of the study. The habitat classification scheme used in this evaluation is one that was developed by Dethier (1990, Table C.1).

Part III, the Modification section, specifies habitat modification, based on the key word list mentioned in the text (Table 1) and attempts to identify the nature of the project (mitigation or non-mitigation). The initial key word list was used to evaluate papers, and was added to when we came across studies that discussed modifications not included on our list. Part IV, Monitoring, denotes whether or not monitoring of the site had taken place prior to, or after the modification, or both.

In an attempt to create a method of standardized data evaluation that would allow for objective comparison between papers and for an overall analysis of the body of literature, we focused a great deal on the structuring of the Impacts section (Part V) and the Data Evaluation (Part VI). The parameters considered in the Impacts of Modification section were initially grouped as one single category, but through the course of evaluation, these parameters separated themselves into two distinct categories: alterations that occurred as a result of habitat modifications and responses to those alterations by the salmonids. Here again the lists were added to as we encountered studies of parameters not included on the list. Subsequently, we also decided to distinguish between direct and indirect studies of these parameters and whether they were directly or indirectly impacted. In Part V, instead of a "yes/no" response format, queries are answered with D (Direct), I (Indirect), N (No), or B (Benign).

In the case of a study, Direct means that the parameter was intentionally studied. In the case of impacts, Direct means there was an unequivocal impact of causal origin; cause and effect were unambiguous. An Indirect study means that the parameter was not intentionally studied, but that observations were made. An Indirect impact means that there was a correlative determination or inference of impacts with respect to that parameter. N means that the parameter was not studied or it was not known if the parameter was studied or impacted. Benign, on the other hand, signifies that there was conclusive evidence that the parameter was NOT impacted by habitat manipulation.

In Data Evaluation, questions were designed to demonstrate the quality of data in a manner that was as non-subjective as possible. The Bottom Line, Part VII, on the other hand was included to allow for a more subjective summary of the paper that could be used for quick reference.

Dethier, M.N. 1990. A marine and estuarine habitat classification system for Washington State. Nat. Heritage Prog., Wash. State. Dept. Nat. Res. Olympia, WA.

Appendix Table C1. Habitat classification scheme utilized for literature evaluation of estuarine habitat modification; adapted from Dethier (1990).

I. Estuarine
   A. Intertidal
      1. bedrock: open
      2. hardpan
      3. mixed coarse: open
      4. gravel: open
      5. sand: open
      6. mixed-fine: open, eulittoral
      7. mud: partly enclosed and enclosed
      8. mixed-fine and mud
         i. open, backshore (marshes)
         ii. lagoon
         iii. channel-slough
      9. organic
      10. artificial
      11. reef
   B. subtidal
      1. bedrock-boulder: open
      2. cobble: open
      3. mixed-coarse: open
      4. sand
         i. open
         ii. partly enclosed
      5. mixed-fines: open
      6. mud
         i. open
         ii. partly enclosed
      7. sand and mud: channel
      8. organic
      9. artificial
      10. reef
   C. neritic
      1. water column

Paper Categorization Form

Author(s):____

____

Title:____

____

Source:____

____

Date:__________

I. GENERAL STUDY INFORMATION (circle choice)

Paper Category: Original Research/Synopsis-Review/Other

Peer review: formal/informal/unknown

Length of study interval:

Future studies

Is this part of a long term study?: yes/no
Are future studies planned?: yes/no

II. DESCRIPTIVE CHARACTERISTICS (circle choice)

Eco-Region:
Alaska–Central Gulf to Kodiak
British Columbia–Johnson Straits to Southeast Alaska
Puget Sound and the Straits of Georgia
Coastal Oregon and Washington
Northern California–San Francisco Bay to the Oregon border

Species: chum/chinook/pink/coho/sockeye/steelhead

Life history stage: fry/juvenile/smolt/adult

Habitat (circle choice or fill in blank)

System: Estuarine

Subsystem: Intertidal/Subtidal/Whole system/Neritic/NA

Substrata (see list)**:**

Energy: open/partly enclosed/lagoon/channel-slough/
whole system/NA

Modifiers (circle choice)

Salinity: hyperhaline/euhaline/mixohaline/whole system

vegetation: low marsh/high marsh/seagrass/macroalgae
diatom mat/whole system/NA

III. MODIFICATION

Type (see list): ___________________________

Age (# of years): <1 / 1-5 / 5-25 / >25

Mitigation (circle one)

Is this a mitigation project: yes/no
If not, is mitigation involved: yes/no

IV. MONITORING (circle choice)

Pre-modification: yes/no
Performed by: investigator/someone else/not evident

Post-modification: yes/no
Performed by: investigator/someone else/not evident

VI. DATA EVALUATION

Were studies done as part of project to measure impacts
yes/no

Objective Criteria for data evaluation

FOR WHAT PARAMETERS:

Was a stated hypothesis tested?______________________________

____

Was there an appropriate (to the hypothesis) statistical sampling design?______________________________

____

Was statistical testing involved?______________________________

____

Was sampling adequate over time and space?____________________

____

Was there sufficient replication?______________________________

____

VII. Bottom Line:______________________________

____

____

____

APPENDIX D. SUMMARY OF RESULTS FROM EVALUATION OF DIRECT LITERATURE

ANALYSIS OF DIRECT REFERENCES

I. GENERAL STUDY INFORMATION

Paper Category:	
Original research	83.3% (20)
Synopsis-review	16.7% (4)
Other	0
Peer review:	
Formal	12.5% (3)
Informal	37.5% (9)
Unknown	50% (12)
Length of study interval:	
<1 year.	45.8% (11)
1-2	41.7% (10)
3-5	8.3% (2)
6-10	4.2% (1)
>10	0
Future studies	
Is this part of a long term study?	
yes	54.2% (13)
no	45.8% (11)
Are future studies planned?	
yes	16.7% (4)
no	83.3% (20)

II. DESCRIPTIVE CHARACTERISTICS

Eco-Region:	
Alaska - Central Gulf to Kodiak	0
British Columbia - Johnson Straits to Southeast Alaska	33.3% (8)
Puget Sound and the Straits of Georgia	54.2% (13)
Coastal Oregon and Washington	0
Northern California - San Francisco Bay to the Oregon border	12.5% (3)
Species:	
chum	66.7% (16)
chinook	45.8% (11)
pink	29.2% (7)
coho	33.3% (8)
sockeye	8.3% (2)
steelhead	0

Life history stage:

fry	45.8% (11)
juvenile	50.0% (12)
smolt	0
adult	4.2% (1)

Habitat system:

estuarine

Subsystem:

intertidal	37.5% (9)
subtidal	4.2% (1)
whole system	8.3% (2)
neritic	20.8% (5)
n/a	12.5% (3)

Substrata:

mixed coarse	4.2% (1)
sand	16.7% (4)
mixed-fine to mud	20.8% (5)
gravel	4.2% (1)
water column	20.8% (5)
n/a	33.3% (8)

Energy:

open	8.3% (2)
partly enclosed	16.7% (4)
lagoon	0
channel-slough	20.8% (5)
whole system	41.7% (10)
n/a	12.5% (3)

Modifiers

Salinity:

hyperhaline	0
euhaline	4.2% (1)
mixohaline	95.8% (23)
whole system	0

Vegetation:

low marsh	4.2% (1)
high marsh	8.3% (2)
seagrass	12.5% (3)
macroalgae	0
diatom mat	0
whole system	20.8% (5)
n/a	54.2% (13)

III. MODIFICATION

Type:

Bank Modification:		
	stabilization	0
	dike	0
	levee	0
	embankment	0
	revetment	0
	bulkhead	0
	riprap	4.2% (1)
	training walls	4.2%
Seabed Modification:		
	log storage	4.2%
	excavation	4.2%
	dredging	25.0% (6)
	intake channel	4.2% (1)
	filling/dredge disposal	4.2%
	rip channel	0
	sea channel	0
	navigation channel	0
	canal	0
	wetland drainage	0
Flow Control:		
	freshwater diversion	8.3% (2)
	jetty	0
	weir	0
	hydraulic structure	0
	tidegate	0
	dam	0
	flood control	0
	salinity intrusion	0
Erosion Control:		
	seawall	0
	groin	0
	coast defense	0
	coastal erosion	0
Habitat Improvement:		
	artificial islands	8.3% (2)
	wetland construction	4.2% (1)
	artificial reef	4.2%
Artificial Harbor:		
	port installation	20.8% (5)
	marina	4.2% (1)

Age (# of years):	<1	37.5% (9)
	1-5	25.0% (6)
	5-25	29.2% (7)
	>25	8.3% (2)

Mitigation (circle one)

Is this a mitigation project: yes..25% no..75%
If not, is mitigation involved: yes..0 no..75%

IV. MONITORING (circle choice)

Pre-modification:	yes	41.6%	no	58.3%
Performed by:	investigator			16.7%
	someone else			16.7%
	not evident			8.3%
Post-modification:	yes	79.2%	no	20.8%
Performed by:	investigator			50.0%
	someone else			20.8%
	not evident			8.3%

Were studies done as part of project to measure impacts?

yes	75%
no	25%

For what percentage of papers?

Was a stated hypothesis tested	16.7% (4)
Was there an appropriate statistical sampling design	8.3% (2)
Was statistical testing involved	62.5% (15)
Was sampling extensive over time and space	75.0% (18)
Was there replication	70.8% (17)

APPENDIX E. SUMMARY OF EVALUATION OF IMPACTS STUDIES AND DOCUMENTED BY CATEGORY OF IMPACT

Appendix Table E1. Habitat alterations and related responses.

Alterations	Related responses—Number of studies									
	Abundance	ST Survival	LT Survival	Physiology	Fish Growth	Feeding	Schooling	Mig. Rate	Res. Time	Distribution
Hydrology	4	2	1	0	1	1	0	0	1	0
Temperature	0	0	0	0	0	0	0	0	0	0
Salinity	0	0	0	0	0	0	0	0	0	0
Turbidity	0	4	0	0	0	0	0	0	0	2
Pollutants	0	3	0	0	0	0	0	0	0	0
Light	3	0	0	0	0	0	0	2	0	1
Dissolved O_2	0	0	0	0	0	0	0	0	0	0
Habitat morphology	8	0	0	0	1	2	0	0	1	3
Obstruction	0	0	0	0	0	0	0	0	0	0
Primary production	0	0	0	0	0	0	0	0	0	0
Prey resources	0	0	0	0	0	2	0	0	0	0
Predators	0	2	0	0	0	0	0	0	0	0
Competitors	0	0	0	0	0	0	0	0	0	0

Appendix Table E2. Percentages of alterations and responses studied/impacted.

	Studied			Impacted			
	D	I (%)	N	D	I (%)	N	B
Alterations							
Hydrology	20.8	4.2	4.2	20.8	0	8.3	0
Temperature	4.2	8.3	0	0	8.3	4.2	0
Salinity	8.3	0	0	4.2	0	4.2	0
Turbidity	12.5	12.5	0	12.5	4.2	8.3	0
Pollutants	12.5	16.7	0	4.2	0	8.3	16.7
Light	12.5	0	0	4.2	8.3	0	0
Dissolved Oxygen	8.3	4.2	0	8.3	4.2	0	0
Habitat Morphology	33.3	8.3	4.2	29.2	12.5	4.2	0
Obstruction	0	0	0	0	0	0	0
Primary Production	16.7	8.3	4.2	0	16.7	12.5	0
Prey Resources	25	16.7	0	16.7	20.8	4.2	0
Predators	12.5	16.7	4.2	0	12.5	8.3	12.5
Competitors	0	16.7	0	0	8.3	8.3	0
Responses							
Abundance	54.2	12.5	0	37.5	25	4.2	4.2
ST Survival	41.7	0	0	16.7	0	8.3	16.7
LT Survival	4.2	0	0	0	4.2	0	0
Physiology	8.3	0	0	4.2	0	0	4.2
Fish Growth	4.2	12.5	0	0	12.5	4.2	0
Feeding	29.2	0	0	8.3	12.5	4.2	4.2
Schooling	0	0	0	0	0	0	0
Migration Rate	12.5	0	0	0	8.3	4.2	0
Residency Time	16.7	4.2	0	0	16.7	4.2	0
Distribution	29.2	8.3	0	20.8	8.3	4.2	4.2

Appendix Table E3. Data evaluation.

	Stated hypothesis	Statistical sampl. des.	Statistical testing	Sampling over time & space	Replication
Alterations					
Hydrology	0	0	0	0	0
Temperature	0	0	4.2	4.2	4.2
Salinity	0	0	8.3	4.2	8.3
Turbidity	0	0	8.3	8.3	8.3
Pollutants	4.2	0	16.7	16.7	16.7
Light	0	0	8.3	8.3	8.3
Dissolved Oxygen	0	0	4.2	4.2	4.2
Habitat Morphology	0	0	4.2	4.2	4.2
Obstruction	0	0	0	0	0
Primary Production	0	0	12.5	20.8	12.5
Prey Resources	4.2	4.2	16.7	16.7	16.7
Predators	0	0	8.3	8.3	8.3
Competitors	0	0	0	0	0
Responses					
Abundance	8.3	8.3	41.7	45.8	45.8
ST Survival	4.2	0	25	20.8	20.8
LT Survivial	0	0	4.2	4.2	4.2
Physiology	4.2	0	4.2	8.3	4.2
Fish Growth	0	0	4.2	4.2	4.2
Feeding	4.2	4.2	8.3	16.7	20.8
Schooling	0	0	12.5	0	0
Migration Rate	0	0	0	8.3	12.5
Residency Time	0	0	0	0	0
Distribution	4.2	0	25	25	37.5