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**FISH AND THEIR EPIBENTHIC PREY  
IN A MARINA AND ADJACENT MUFLATS  
AND EELGRASS MEADOW  
IN A SMALL ESTUARINE BAY**

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## ABSTRACT

We investigated the biomass of plants and the abundance of fish, Dungeness crab and small epibenthos in four estuarine habitat types (marsh, protected mudflat, exposed mudflat, eelgrass meadow) in a Pacific Northwest bay for the purpose of evaluating the relative importance of these habitats to fisheries resources. Twelve sampling trips conducted in spring-early autumn 1987 focused particularly on the density of juvenile salmon and their prey. The marsh (dominated by *Scirpus maritimus* and *Triglochin maritimum*) was probably not utilized directly by fish or crabs because of the high elevation of the site. In addition, few prey taxa preferred by juvenile salmon were collected from the marsh. The protected mudflat (confined within a marina) contained a greater biomass of sediment-associated microalgae and higher densities of salmon prey as compared to the mudflat exposed to wind driven waves. In addition, plant biomass and prey densities peaked up to 4 weeks earlier on the protected mudflat as compared to the exposed mudflat. Both mudflat sites showed spring peaks in plant biomass, juvenile salmon density and salmon prey densities up to 4 weeks earlier than the eelgrass site. Fish densities, species richness and crab density in the eelgrass site were sustained at or near maximum levels for most of the summer (May-September). In contrast, maxima in fish and prey densities lasted 2-4 weeks in spring (March-April) on the mudflats. Maximum mean fish density (1,150 fish 100 m<sup>-2</sup>) and species richness (18.7 seine sample<sup>-1</sup>) recorded in the eelgrass bed exceeded that on the mudflats by 2.8 and 2.4 times, respectively. Crabs were never abundant (maximum = 0.1 individuals 100 m<sup>-2</sup>) on either mudflat, but were abundant (mean = 1.9 - 31.4 individuals 100 m<sup>-2</sup>) in eelgrass in April-August. Concordance between temporal variations in plant biomass and prey, fish and crab densities was relatively strong. We conclude that the mudflats are important for a short period early in spring for feeding of juvenile outmigrating salmon, and that the eelgrass meadow is important for an extended period in summer, primarily for habitat and food for other fish and crabs.

## INTRODUCTION

Estuarine habitats in the Pacific Northwest provide food and refuge for a variety of commercially and recreationally important fish and invertebrates (Thom 1987). In particular, estuarine habitats form important refuges with abundant food supplies for economically valuable resources such as Dungeness crab (*Cancer magister*) and outmigrating juvenile Pacific salmon (*Oncorhynchus* spp.) in spring and early summer (Congleton and Smith 1977, Levy and Northcote 1982).

Understanding the importance of various habitats to fisheries resources is a primary concern in a time when the abundance of many of these resources is dwindling. Pressure on the resource from overharvesting, and degradation and loss of critical habitat are responsible for declining fisheries stocks. In Northwest estuaries, habitat degradation and losses are significant, particularly in urban centers (e.g., a 90% loss of wetland habitat in the Duwamish River estuary in Seattle; Blomberg et al. 1988). Concomitant declines in aquatic resources, in particular Pacific salmon that utilize estuarine habitats during juvenile outmigration, are well documented (Simenstad et al. 1982).

The present study was conducted to evaluate the importance of a high intertidal mudflat, confined within a marina, to juvenile salmon and Dungeness crabs. This evaluation was needed to determine some of the environmental impacts of dredging the flat in order to enlarge the marina for boat moorage, and to develop alternatives to compensate for loss of high mudflat habitat. Early in the study, we decided to consider the potential of establishing an eelgrass meadow as part of the mitigation plan. The existing conditions and proposed development plan presented the opportunity to address the following more general ecological questions related to the support of fisheries resources by selected habitats:

- (1) How do high intertidal mudflats differ from eelgrass meadows;
- (2) how does the marina flat (a system relatively protected from physical disturbance) differ from the relatively unprotected flats outside the marina; and
- (3) what are the quantifiable relationships between vegetation characteristics, juvenile salmon prey resources and major predators (i.e., fish and crabs) in the system?

In a broader perspective, the study investigated the effects of marina development on nearshore ecosystems and added to the understanding of the relationship between habitat characteristics and selected biological resources important in Pacific Northwest estuaries.

We investigated the questions by sampling benthic vegetation characteristics, fish prey resources (i.e., epibenthos) and fish assemblages within four habitats in Drayton Harbor, Washington, during an 8-month period in 1987. The habitats included a marsh, a mudflat

and adjacent steeply sloping mudflat edge within the confines of a marina (Blaine marina), a mudflat outside the marina, and an eelgrass meadow. The three primary habitats represent the most prominent benthic habitats occurring in northwest estuaries (Thom 1987). While the study focused on juvenile salmon and their prey resources, it also documented aspects of the overall fish assemblage structure that helped define habitat differences. Sampling over several seasons was carried out to evaluate temporal patterns in the vegetation and fauna.

## STUDY AREA

Drayton Harbor is a small (1,104 ha) estuary located on the eastern shoreline of the southern Strait of Georgia (Figure 1). It is a shallow embayment; intertidal and shallow subtidal zones encompass approximately 67% of the area. Much of this area (33%) is vegetated by eelgrass (*Zostera marina*, *Zostera japonica*). Fisheries resources, including Dungeness crab, Pacific herring (*Clupea harengus pallasii*) and salmon are abundant in Drayton Harbor (Evans-Hamilton and D.R. Systems 1987). Salmon runs occur in two streams that enter at the southern portion of Drayton Harbor. In addition, salmon populations from rivers and streams to the north and south probably spend time in Drayton Harbor during outmigration. The eelgrass in the bay has been identified as an important spawning habitat for herring (Evans-Hamilton and D.R. Systems 1987). Shorebirds and waterfowl are abundant much of the year, and are probably utilizing invertebrate food resources on the flats and in the channels. Salinity in Drayton Harbor was relatively high (>25 ppt) during our studies. Water temperature varied from a low in March of 8°C to a high of 24°C in July. The Washington Department of Ecology (unpublished data) has found that nutrients reach very low concentrations (less than 1 µM nitrate nitrogen) for extended periods during summer. Tides are mixed semi-diurnal with a mean annual range of 1.8 m. With the exception of small areas utilized for marinas and historical export of wood products, the bay is relatively undisturbed.

Blaine Marina is primarily a basin (4-m deep MLLW) dredged from former eelgrass meadows and mudflats. The only natural shallow habitat remaining in the marina is a small (ca. 0.3 ha) marsh and a high (+1.8 m MLLW) intertidal mudflat (5.1 ha), both located at the inner (northeastern) end of the marina (Figure 1). Although boat wakes, debris, organic and inorganic wastes and other factors commonly associated with marina's probably have some impact on the marina habitats, we never encountered visible signs of pollution (i.e., oil slicks, masses of debris) on the flat. The marsh tended to accumulate debris

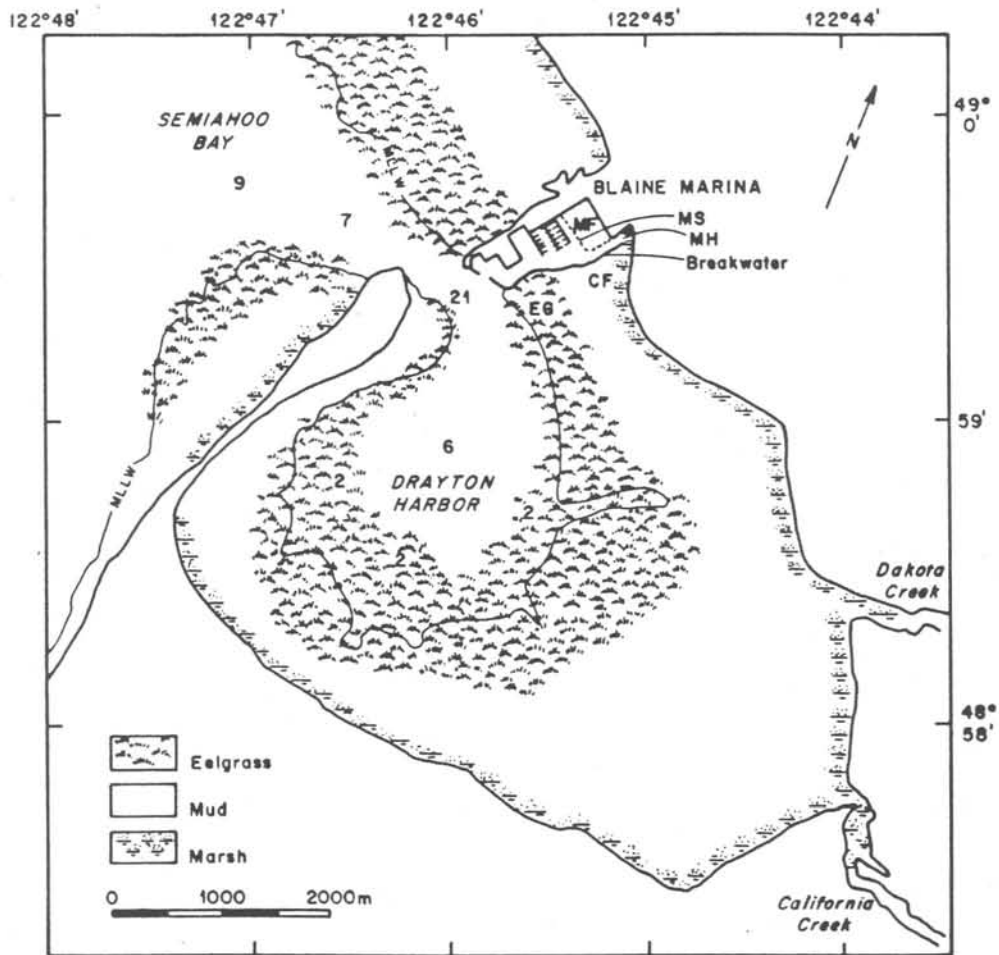


Figure 1. Location of benthic/epibenthic and fish sampling sites in Drayton Harbor, Washington.

because of its confined location. Water from the bay entered the marina primarily at the western (deep water) end. However, during extreme high tides, water (and, potentially, aquatic organisms) entered the marina via a small channel located in a breach at the east end of the breakwater (Figure 1). Winds were predominantly from the south in spring and early summer. Hence, when compared to the flat located in Blaine Marina, the other study sites in Drayton Harbor experienced obvious wind-generated turbulence (i.e., very muddy water and high waves) (Figure 1).

## MATERIALS AND METHODS

### Study Sites

Our studies were conducted during 12 field trips made between 4 March and 20 October 1987. Trips were made biweekly in March-May, and monthly thereafter. The study sites were located in habitats as follows: the small (0.3 ha) salt marsh dominated by *Scirpus maritimus*, *Triglochin maritimum* and *Distichlis spicata* located at the extreme eastern end of the marina (MH); the top of the marina mudflat (1.8 m MLLW) (MF); the sloping seaward edge (0.9 m MLLW) of the mudflat in the marina (MS); on the mudflat (1.8 m MLLW) immediately adjacent to the marina in Drayton Harbor (CF); and in the eelgrass bed (0.6 m MLLW) 200 m south of the entrance to the marina (EG) (Figure 1). Substrata (fine sand, silt, clay mixture) and elevation were observed to be very similar between the two mudflat sites.

### Vegetation Sampling

Ten replicate samples for vegetation were collected from random points on MF and CF, and five samples were collected from the MH, MS and EG sites. The sampling points were marked permanently with either thin bamboo stakes or plastic tent stakes to which were attached small (1-2 cm diameter) plastic fishing bobbers using 2-m lengths of monofilament fishing line. All above-ground attached macrophytic vegetation was removed from within a 0.1 m<sup>2</sup> square quadrat at both the MH and EG sites. Cores (1-cm diameter surface x 1-cm deep) were collected from the MF, CF and MS sites. All samples were kept in the dark on ice and frozen upon return to the laboratory. In the laboratory, macrophyte material was separated by species and the dry weight determined for each species after drying at 80°C. The sediment cores were ground with a mortar and pestle and extracted overnight in

90% acetone. Chlorophyll *a* concentration was determined using a fluorometer (Turner model 112) and calculated based on the formulas in Lorenzen (1966).

### Epibenthos Assemblage Sampling

Epibenthic fauna that may serve as prey for fish were sampled during seven field trips made in March-June, coincident with the occurrence of epibenthic-feeding juvenile salmon in the estuary. Sampling was conducted within each study site during each field trip, except at site MH; sampling in the marsh could not be carried out during 9 of the 12 trips because the water level at high tide was too low to sample effectively.

The epibenthos within the laminar or lower turbulent layer over 179 cm<sup>2</sup> of the sediment surface was suctioned with a battery-powered epibenthic suction pump and retained on a 0.125-mm sieve. This pump effectively samples epibenthic crustacea in similar habitats (Thom et al. 1986, Simenstad et al. 1988). Samples of epibenthos were collected as close as possible to the vegetation samples. Therefore, 10 replicate samples were collected on MF and CF, and 5 replicate samples were collected at the other sites.

All samples were preserved in 5% formalin buffered with borax and later (ca. 14 d) transferred to 45% isopropyl alcohol preservative. The number of taxa and abundances of animals allowed us to process only 6 replicates of the 10 from MF and CF and 3 of the 5 replicates from the other sites within the time and effort allocated to this study. In the laboratory, the samples were washed on 0.253-mm screens. In cases where substantial amounts of fine sediments were taken with the sample, the animals were separated from the sediments by panning. Epibenthic animals were then sorted to species and life history stage (e.g., nauplii, copepodid, male, gravid female) and enumerated. Finally, the blotted wet weight of each species and life history stage was recorded to the nearest 0.1 mg.

### Fish Assemblage Sampling

During each sampling trip, three replicate beach seine collections were made at MF and CF at high tide, and at EG during slack low tide. The tide was never high enough to effectively seine the MH site. The 37-m seine was affixed with a 7-mm mesh bag and set 30 m from the water line from the back of a small boat. The seine was hauled to shore by two, 2-person teams. Small (e.g., <1 liter) catches were preserved in their entirety in 10% saltwater-buffered formalin; larger catches were subsampled volumetrically. Very large fish were counted, measured, weighed and released alive.

Stomach contents of juvenile chum (*Oncorhynchus keta*) and juvenile chinook (*O. tshawytscha*) salmon from representative collections were analyzed systematically using standardized procedures that quantify the occurrence, numeric composition, and gravimetric composition of prey (Terry 1977). Preserved fish were measured for fork length (FL) and weighed to the nearest mg. Stomachs, consisting of the region from the esophagus to just prior to the pylorus, were dissected from the fish. Stomach contents were removed as a bolus, blotted on tissue paper and weighed to the nearest mg. Qualitative distinctions were recorded for stomach fullness (1=empty to 7=distended) and digestion (1=complete to 6=no digestion). Prey organisms were sorted to the lowest taxonomic level, typically order, although all harpacticoids and gammarid amphipods were identified to species, when possible. Each prey category was enumerated and weighed to the nearest 0.1 mg. Precision in identifying food items depended on the life history stage of the prey and the degree of digestion. Thus, food habits often encompassed several taxonomic levels for perhaps the same or homologous species.

### Data Analysis

All data for epibenthos and fish stomach analyses were recorded in National Oceanographic Data Center (NODC) format #100, utilizing the NODC taxonomic code. Tabulation and summary statistics of epibenthic crustacea sample data were standardized to standing stock on a unit area ( $m^2$ ) basis using mainframe computer programs designed for the NODC format.

A modified Index of Relative Importance (IRI, Pinkas et al. 1971) was used to describe salmonid food habits: An IRI value for each prey item was computed, where  $IRI = (\% \text{ frequency occurrence } [\% \text{ numerical composition } + \% \text{ gravimetric composition}])$  and standardized to  $\%$  total IRI.

The general null hypothesis we tested was that there was no difference among habitats in the mean values of a selected set of the measured parameters over the study period. We used the Wilcoxon test, which ranks differences between mean values paired by sampling date, as an *a priori* test of this hypothesis (Sokal and Rohlf 1973). The test does not effectively delineate habitat-specific seasonal differences we encountered during the study period. These differences were evaluated within sampling dates, *a posteriori*, with the Least Significant Difference (LSD) test at the 95% confidence level (Snedecor and Cochran 1980).

## RESULTS

## Vegetation Characteristics of the Marsh and Mudflats

The salt marsh consisted primarily of *Scirpus maritimus*, *Triglochin maritimum*, *Distichlis spicata* and *Salicornia virginica*. *Scirpus maritimus* consistently had the greatest mean live standing stock, with the maximum of 460 g dry wt m<sup>-2</sup> in July. Mean total biomass increased steadily from a low of 501 g dry wt m<sup>-2</sup> on 4 March to a maximum of 1024 g dry wt m<sup>-2</sup> on 22 July.

The flats contained sediment-associated microalgae. Green macroalgae, primarily *Enteromorpha* spp., was abundant (chlorophyll cores included portions of *Enteromorpha* attached to sediment grains) during much of the spring and summer. The MF site contained extensive patches of the yellow-green alga *Vaucheria* sp. Seaweed taxa including the finely branched red algae *Ceramium pacificum* and *Chondria dasyphylla*, and the green bladed alga *Ulva fenestrata* occurred at site EG and were always less than 10% of the total vegetation biomass at EG.

Mean chlorophyll *a* values were significantly greater at MF as compared to MS and CF for the study period (Table 1). Chlorophyll *a* concentration showed a large degree of

Table 1. Results of the Wilcoxon test for differences in mean parameter values between habitats. -- = not tested; ns = not significantly different; \* = significantly different at the 10% level; \*\* = significantly different at the 5% level; \*\*\* = significantly different at the 1% level. The direction of the difference is indicated in parentheses under the test results.

Parameter	Site pairs					
	MF vs MS	MF vs CF	MF vs EG	MS vs CF	MS vs EG	CF vs EG
Chlorophyll <i>a</i>	*** (MF>MS)	*** (MF>CF)	--	* (MS<CF)	--	--
Total Epibenthos	ns	ns	ns	ns	ns	ns
Salmon Prey	ns	** (MF>CF)	ns	** (MS>CF)	ns	** (CF<EG)
Fish Density	--	ns	ns	--	--	* (CF<EG)
Salmon Density	--	ns	ns	--	--	* (CF<EG)
Fish Spp. Richness	--	ns	*** (MF<EG)	--	--	*** (CF<EG)

variability over the study period (Table 2). An early March peak was seen at the MF and MS sites. In addition, there was a pronounced peak on the MF in late April. Chlorophyll *a* increased steadily from early March to a mid-April maximum at the CF site (Table 2). In addition, values at MS were significantly greater than those at CF (Table 1).

### Epibenthos Assemblages

Densities of epibenthic organisms reached a maximum at MF in early March and late April, and were greatest among all sites in early March (Table 2). Maximum densities occurred at MS in mid-March and late April. Density was greatest at EG in mid- to late April (Table 2). Mean total epibenthos density was not significantly different among the sites for the study period (Table 1). CF densities followed a seasonal pattern similar to that of the MF site; however, densities were significantly different among some sites during late March through early April and in late April (Table 2). Of note are the high densities in the EG site during April.

Harpacticoid copepods dominated both numerical and gravimetric composition of the epibenthos, representing 68.6%, 62.4%, 65.5% and 86.1% of the mean total density, and 62.9%, 53.7%, 66.4% and 72.6% of the mean total standing crop for the MF, CF, MS and EG sites, respectively. Nematodes were also abundant, and gammarid amphipods were dominant by weight. The harpacticoid taxa *Harpacticus uniremis*, *H. sp.-uniremis* group, *Heterolaophonte variabilis*, *Huntemannia jadensis*, *Nannopus palustris*, *Stenhelia* sp. A, and *Mesochra* cf. *lilljeborgi* dominated the assemblages on the littoral flats (sites MF and CF). Ectinosomatids, *H. uniremis*, *H. sp.-uniremis* group, *H. jadensis* and *Leimia vaga* dominated the MS assemblage. The EG assemblage was dominated by *H. uniremus*, *H. sp.-uniremus* group, *Zaus* sp. and *Tisbe* spp. Juvenile salmon feed selectively on several of these epibenthic crustacean taxa, e.g. harpacticoids of the *H. uniremis* group and *Tisbe* spp., and gammarid amphipods *Paracalliopiella pratti*, *Corophium* spp. and *Eogammarus confervicolus* (Simenstad et al. 1982, Simenstad and Wissmar 1985, Simenstad and Cordell unpublished data). This functional "prey" group of salmon prey taxa reached maximum density in early March at MF, in late March at MS, and in late-April at EG (Table 2). In contrast, the CF site contained very low densities of these taxa throughout the study period. The MF, MS and EG sites contained significantly greater mean prey densities than CF over the entire sampling period (Table 1). Differences in prey density among sites within certain sampling dates were pronounced (Table 2). The MF site had the highest

Table 2. Mean values for sampled parameters. The results of the LSD test within each date are indicated by the superscript letter. Mean values that were not significantly different have the same letter. No letter is shown when all mean values are not significantly different. Fish species richness and crab density were not tested. (- = not sampled.)

Date	Chl. <i>a</i> (x 10 <sup>2</sup> mg m <sup>-2</sup> )			Epibenthos density (x 10 <sup>4</sup> m <sup>-2</sup> )				Salmon prey density (x 10 <sup>3</sup> m <sup>-2</sup> )				Fish density (100 m <sup>-2</sup> )			Juvenile salmon density (100 m <sup>-2</sup> )			Fish species richness (520 m <sup>-2</sup> )			Crab density (100 m <sup>-2</sup> )		
	MF	MS	CF	MF	MS	CF	EG	MF	MS	CF	EG	MF	CF	EG	MF	CF	EG	MF	CF	EG	MF	CF	EG
5 Sept	9.4 <sup>a</sup>	8.0 <sup>a</sup>	2.6 <sup>b</sup>	4.3	0.6	2.4	1.7	18.2	2.5	1.4	0.8	34	41	9	0	0	0	2.7	3.0	3.7	0	0	0
20 March	7.3	3.2	3.6	1.4 <sup>a</sup>	5.7 <sup>b</sup>	0.9 <sup>a</sup>	1.6 <sup>a,b</sup>	7.9 <sup>a</sup>	27.8 <sup>b</sup>	0.7 <sup>a</sup>	1.7 <sup>a,b</sup>	26	41	18	0	0	0	2.3	3.0	13.7	0	0.1	1.0
3 April	2.7	4.0	4.1	0.6 <sup>a</sup>	1.8 <sup>b</sup>	3.4 <sup>a</sup>	0.5 <sup>b</sup>	4.0	5.2	<0.1	3.0	32	27	18	12 <sup>a</sup>	0.2 <sup>b</sup>	0.7 <sup>b</sup>	3.3	3.0	15.0	0	0	1.9
15 April	3.5	2.2	5.9	1.7	2.0	2.9	10.9	0.9 <sup>a</sup>	2.0	0.2	88.5	75	4	63	0	0	0.7	2.3	3.3	18.3	0	0.1	3.5
29 April	14.0 <sup>a</sup>	2.0 <sup>b</sup>	5.5 <sup>b</sup>	8.3 <sup>a</sup>	2.7 <sup>b</sup>	5.5 <sup>c</sup>	17.8 <sup>d</sup>	0.3 <sup>a</sup>	1.3 <sup>a</sup>	0.1 <sup>a</sup>	139.4 <sup>b</sup>	296	26	72	0.3 <sup>a</sup>	7.3 <sup>b</sup>	16.3 <sup>b</sup>	3.3	4.3	16.0	0	0	9.0
14 May	4.5	1.3	2.0	0.7	4.2	-	5.4	0 <sup>a</sup>	0 <sup>a</sup>	-	18.7 <sup>b</sup>	245 <sup>a</sup>	45 <sup>a</sup>	1374 <sup>b</sup>	4.3 <sup>a</sup>	1.3 <sup>a</sup>	8.7 <sup>b</sup>	7.7	4.7	18.7	0	0	6.3
26 May	5.2	0.7	1.9	-	-	-	-	-	-	-	-	84 <sup>a</sup>	27 <sup>a</sup>	779 <sup>b</sup>	0.3	0.2	0.2	5.0	4.0	12.3	0	0.1	6.4
23 June	6.0	2.3	3.5	1.1	0.7	3.1	2.7	0	0.7	0	0.3	92 <sup>a</sup>	31 <sup>a</sup>	1004 <sup>b</sup>	0.5	0.2	0.2	4.7	5.7	12.7	0	0	4.6
22 July	3.7	1.5	1.0	-	-	-	-	-	-	-	-	75	30	373	0	0.2	0	4.0	4.3	14.0	0	0	6.2
21 August	3.3	0.8	3.1	-	-	-	-	-	-	-	-	129 <sup>a</sup>	964 <sup>b</sup>	1141 <sup>b</sup>	0.2	0	0	3.7	3.3	6.7	0	0	31.4
16 Sept	6.5	1.1	4.6	-	-	-	-	-	-	-	-	408 <sup>a</sup>	344 <sup>a</sup>	1150 <sup>b</sup>	0	0	0	2.3	3.7	7.0	0	0	0.1
15 Oct	3.9	2.5	3.2	-	-	-	-	-	-	-	-	4	3	6	0	0	0	3.0	1.7	5.0	0	0	0

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mean density in early March as compared to the other sites. However, owing to high within-site variation, this value was not significantly different from the other sites. The greatest densities in mid-March occurred at the MS site, and EG showed significantly higher densities from mid-April through mid-May.

The epibenthic assemblage in the emergent marsh site (MH), which was sampled twice in March, was dominated numerically by harpacticoids (51.3% of mean total density) and turbellarians (20.2%). A flabelliferan isopod (*Gnorimosphaeroma oregonense*) and the amphipod *Eogammarus confervicolus* accounted for 30.0 and 15.2%, respectively of the total mean standing crop in the marsh samples. The principal harpacticoids in the assemblage were *Tachidius incisipes*, *Nitocra spinipes armata*, *Pseudobradya* sp. and *Heterolaophonte hamondi*.

### Fish Assemblage

The fish assemblage in the eelgrass habitat (EG) consistently contained more species and had a greater mean density as compared to the two littoral flat habitats. The number of species in the EG site ranged from 5 in October to 27 in mid-April. In comparison, number of species in sites MF and CF ranged between 3 and 12 (Tables 2, 3). Surf smelt (*Hypomesus pretiosus*) and Pacific staghorn sculpin (*Leptocottus armatus*) were the most abundant and frequently occurring species in the MF and CF sites throughout the sampling period. Shiner perch (*Cymatogaster aggregata*) and threespine stickleback (*Gasterosteus aculeatus*) were common in the EG habitat, although they did not appear in great abundance until mid-May. Mean densities of these species increased in August with recruitment of young-of-the-year. Starry flounder (*Platichthys stellatus*) were also common in the EG samples, and reached high relative abundances in late July and early August. Yearling and young-of-the-year Pacific herring were abundant in EG in May and June.

Fish densities were relatively low at all sites through mid-April (Tables 2, 3). Densities increased at MF and EG in late April, with the most dramatic increase occurring at the latter site. CF showed maximum fish density in late summer (i.e. mid-August through mid-September). On the basis of an *a priori* test for the entire study period, the only significant difference in fish density was between EG and CF (Table 1); however, on certain sample dates, significant differences did occur among sites, most notably between the eelgrass site and the other sites in May through September (Table 2). CF densities exceeded MF only in mid-August, a period when mats of floating *Enteromorpha* were collected in the beach



Table 3 - cont'd.

Taxa	5 March			20 March			4 April			15 April		
	MF	CF	EG	MF	CF	EG	MF	CF	EG	MF	CF	EG
Scorpaenidae- scorpionfishes												
<i>Sebastes</i> spp.												
Hexagrammidae- greenlings					0.1	2.6	0.1		1.0			2.2
<i>Hexagrammos</i> <i>decagrammus</i>												
<i>H. stelleri</i>												
<i>Ophiodon</i> <i>elongatus</i>	0.1					0.1		0.1	0.2			
Cottidae												0.1
<i>Artedius</i> <i>harringtoni</i>												
<i>Ascelichthys</i> <i>rhodorus</i>						0.1						
<i>Clinocottus</i> spp.												
<i>C. acuticeps</i>			0.3			0.2			0.4			0.2
<i>Enophrys bison</i>					0.3							
<i>Leptocottus</i> <i>armatus</i>	78.1	9.7	8.0	24.7	10.2	2.6	17.4	16.5	2.5	16.3	2.2	5.6
<i>Myoxocephalus</i> <i>polyacanthocephalus</i>									0.3			0.1
<i>Oligocottus</i> spp.						0.1			0.1			0.1
<i>O. maculosus</i>						0.1						
<i>Psychrolutes</i> <i>paradoxus</i>												0.1
Agonidae-poachers												
<i>Agonus</i> <i>acipenserinus</i>						1.1			0.3			0.1
<i>Pallasina barbata</i>			0.1						0.1			
Bothidae-lefteye flounders												
<i>Citharichthys</i> <i>stigmaeus</i>						0.1			0.3			0.3
Pleuronectidae- righteye flounders												
<i>Pleuronectes</i> ( <i>Lepidopsetta</i> ) <i>bilineata</i>			0.1			0.5			0.5			0.3
<i>P. (Parophrys)</i> <i>vetulus</i>					3.5							0.6
<i>Platichthys</i> <i>stellatus</i>		0.1	0.1	0.1	0.4	1.5		0.2	1.1		0.6	1.3
<i>Pleuronichthys</i> <i>coenosus</i>												
<i>Psettichthys</i> <i>melanostictus</i>												
Total species richness	4	4	8	3	6	20	4	5	19	3	5	27
Mean total density (no. m <sup>-2</sup> )	0.3	0.4	0.1	0.3	0.4	0.2	0.3	0.3	0.2	0.8	<0.1	0.6



Table 3 - cont'd.

Taxa	29 April			14 May			26 May			23 June		
	MF	CF	EG	MF	CF	EG	MF	CF	EG	MF	CF	EG
<i>Hexagrammos decagrammus</i>			2.5									
<i>H. stelleri</i>						5.3			2.2			0.3
<i>Ophiodon elongatus</i>												
Cottidae-sculpins	0.1		0.1									0.1
<i>Artedius harringtoni</i>						11.0						0.1
<i>Ascelichthys rhodorus</i>												
<i>Clinocottus</i> spp.			0.1									
<i>C. acuticeps</i>			0.9									
<i>Enophrys bison</i>						2.0			0.1			0.1
<i>Leptocottus armatus</i>	25.6	16.7	21.7	23.7	38.7	14.3	16.1	20.6	8.7	20.1	3.8	7.8
<i>Myoxocephalus polyacanthocephalus</i>						0.1						
<i>Oligocottus</i> spp.			0.1									
<i>O. maculosus</i>						0.5						
<i>Psychrolutes paradoxus</i>			0.4									
Agonidae-poachers												
<i>Agonus acipenserinus</i>			0.1									
<i>Pallasina barbata</i>												0.1
Bothidae-lefteye flounders												
<i>Citharichthys stigmaeus</i>												
Pleuronectidae-righteye flounders												
<i>Pleuronectes (Lepidopsetta) bilineata</i>			0.1									
<i>P. (Parophrys) vetulus</i>			1.6			1.7			3.1			2.2
<i>Platichthys stellatus</i>		0.1	3.2	0.2	0.5	3.1	0.2	0.3	3.6	0.2	0.3	2.4
<i>Pleuronichthys coenosus</i>												0.1
<i>Psettichthys melanostictus</i>				0.1								
Total species richness	6	6	26	12	7	25	7	6	21	6	9	21
Mean total density (no. m <sup>-2</sup> )	3.0	0.3	0.7	2.5	0.5	13.7	0.8	0.3	7.8	0.9	0.3	7.1



Table 3 - cont'd.

Taxa	22 July			21 August			16 Sept			15 Oct		
	MF	CF	EG	MF	CF	EG	MF	CF	EG	MF	CF	EG
<i>Hexagrammos</i>												
<i>decagrammus</i>												
<i>H. stelleri</i>			1.3			2.2			0.1			
<i>Ophiodon</i>												
<i>elongatus</i>												
Cottidae-sculpins			3.9									
<i>Arteidius</i>												
<i>harringtoni</i>			2.0						6.4			
<i>Ascelichthys</i>												
<i>rhodorus</i>												
<i>Clinocottus</i> spp.												
<i>C. acuticeps</i>												
<i>Enophrys bison</i>			1.3									
<i>Leptocottus</i>												
<i>armatus</i>	5.1	14.9	75.3	5.3	4.0	0.1	4.9	4.9	0.6	1.0	2.9	6.6
<i>Myoxocephalus</i>												
<i>polyacanthocephalus</i>			2.6									
<i>Oligocottus</i> spp.												
<i>O. maculosus</i>			1.3									
<i>Psychrolutes</i>												
<i>paradoxus</i>												
Agonidae-poachers												
<i>Agonus</i>												
<i>acipenserinus</i>												
<i>Pallasina barbata</i>												
Bothidae-lefteye												
flounders												
<i>Citharichthys</i>												
<i>stigmaeus</i>												
Pleuronectidae-												
righteye flounders												
<i>Pleuronectes</i>												
( <i>Lepidopsetta</i> )												
<i>bilineata</i>												
<i>P. (Parophrys)</i>												
<i>vetulus</i>												
<i>Platichthys</i>												
<i>stellatus</i>	0.6	1.6	33.6	2.1	17.4	4.1		2.6	1.2	0.5	6.6	
<i>Pleuronichthys</i>												
<i>coenosus</i>												
<i>Psettichthys</i>												
<i>melanostictus</i>												
Total species												
richness	5	6	19	5	4	11	2	5	10	3	4	5
Mean total density												
(no. m <sup>-2</sup> )	0.8	0.3	3.7	1.3	9.6	11.4	4.1	3.4	11.5	<0.1	<0.1	<0.1

seine at CF. Maximum mean fish density and species richness recorded in the EG exceeded that on the mudflats by 2.8 and 2.4 times, respectively.

Juvenile salmon began utilizing nearshore habitats in early April, when chum were captured in abundance over the marina flat (MF). Juvenile chum did not appear in samples from the CF and EG sites until later that month and were abundant at these sites through mid-May (Tables 2, 3). Juveniles of other salmon species (coho, *O. kisutch*; chinook) and anadromous trout (*O. [Salmo] clarki*) were common from late April to June, and were slightly more dense in the eelgrass bed site than either the marina or control flat sites. For the entire sampling period, only EG and CF differed significantly in salmon density (Table 1). However, MF had significantly more salmon in early April as compared to EG and CF. Densities at EG in late April and mid-May were significantly higher than those collected from MF.

Relatively minor changes in the size distribution suggested that the juvenile salmon utilizing Drayton Harbor and the marina were transient rather than resident. The mean fork length of the juvenile chum salmon, for example, was 44.9 mm (sd=3.82) in early April, between 52.3 (sd=11.4) and 53.5 (sd=7.66) mm through April, and between 62.9 (sd=13.6) and 63.2 (sd=14.18) mm in May. Juvenile chinook were principally "fall" chinook (young-of-the-year fry) <100 mm in length, and coho included both young-of-the-year (41.0 mm, sd=1.41) and probably yearlings ("smolts") (106.75 mm, sd=16.28).

Dungeness crabs first appeared in late March. During the study period, crabs were caught at MF only once and only three times at CF. Densities varied between 3 and 9 per 100 m<sup>-2</sup> in mid-April through mid-July at EG (Table 2). Mean crab density at these latter two sites was always <1.0 per 100 m<sup>-2</sup>. The density maximum in the eelgrass in mid-July and August indicated the occurrence of large numbers of young-of-the-year recruits (mean carapace width = 58.0 mm, sd=10.8) in the collections. Because small crabs were noted to readily bury in the mud, the seine samples probably underestimated abundances. Mating pairs were common (mean = 20% of total collection) in mid-late April.

### Vegetation, Prey Resource and Predator Relationships

Chlorophyll *a* concentration, total epibenthos density and salmon prey density at MF and CF exhibited concordant fluctuations over time (Figure 2a-c). In particular, the early decline, the mid- to late-April maximum and the early-May decline in chlorophyll *a* was closely mimicked by total epibenthos density. A maximum total fish density (Figure 2d) late April-early May appeared to correspond with the maximum for total epibenthos.

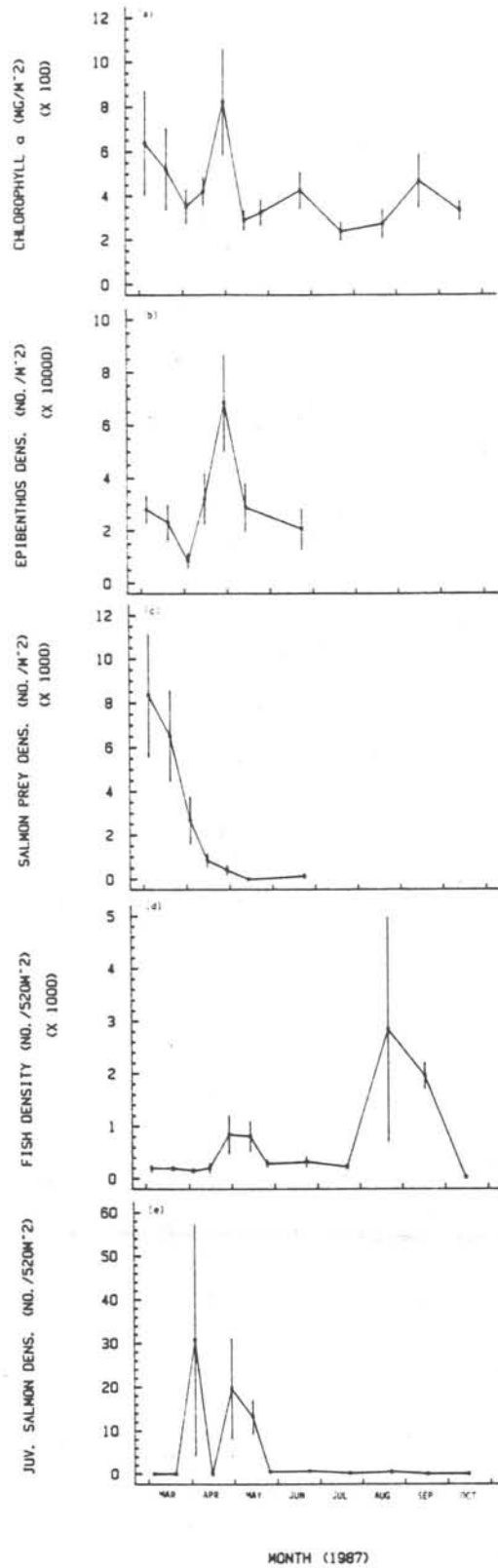


Figure 2. Temporal variations in mean values ( $\pm$  1SE) of biological parameters in the mudflat habitat (sites MF and CF combined): (A) chlorophyll *a* concentration ( $n=25$ ); (B) total epibenthic zooplankton density ( $n=15$ ); (C) salmon prey density ( $n=15$ ); (D) total fish density per beach seine ( $n=6$ ); (E) salmonid density per beach seine ( $n=6$ ).

Maximum density of juvenile salmon (Figure 2e) occurred immediately after a peak in salmon prey density. Total fish density peaked in August-September, during which time mats of *Enteromorpha* were present on the flats, suggesting a potential linkage between the mats and congregations of fish.

The period of most rapid *Zostera* biomass accumulation at site EG (i.e., late April to late May, Figure 3a) was preceded by peaks in total epibenthos (Figure 3b) and salmon prey (Figure 3c) densities. Total fish density (Figure 6d) increased dramatically immediately following the epibenthos maximum. The increase in fish density also corresponded with the period of most rapid increase in *Zostera* biomass. As at the mudflat sites, EG juvenile salmon densities (Figure 3e) increased immediately after the initial increase in epibenthos densities. Of note is the fact that total fish density, fish species richness and Dungeness crab density remained high through the summer, in concordance with the period of greatest eelgrass biomass, and declined rapidly in conjunction with the loss in eelgrass biomass (Table 2).

## DISCUSSION

The mudflat (MF) located inside the marina differed from the other habitats in terms of vegetation, prey resources and fish assemblages. In comparison to the similar flat located outside the marina (CF), the MF site contained greater amounts of sediment-associated algae and densities of salmon prey. In addition, the MF site showed a maximum in early March, prior to peaks in both of the above parameters at CF. On the basis of patterns in relative differences between mean parameter values for the entire study period, the MF site differed from the EG site only in fish species richness and crab density. However, the timing in maxima of mean parameter values was significantly different between the two habitats for total epibenthos density, salmon prey density, fish density and salmon density as well as fish species richness. In general, MF (and CF) vegetation standing stock, prey and juvenile salmon densities peaked earlier in the sampling period as compared to site EG.

It was not possible for us to evaluate the marsh (MH) in terms of fish assemblages because even maximum high tides during our field trips were too low to sample fish in the marsh. We do, however, conclude that direct fish use of this marsh is severely limited because of infrequent opportunities for access. Marsh vegetation standing stock followed the temporal pattern of eelgrass in terms of seasonal increases and decreases. Epibenthos assemblages in the marsh, sampled only a few times by us, were very different in standing stock and taxa composition in comparison to the other sites. In addition, the marsh site

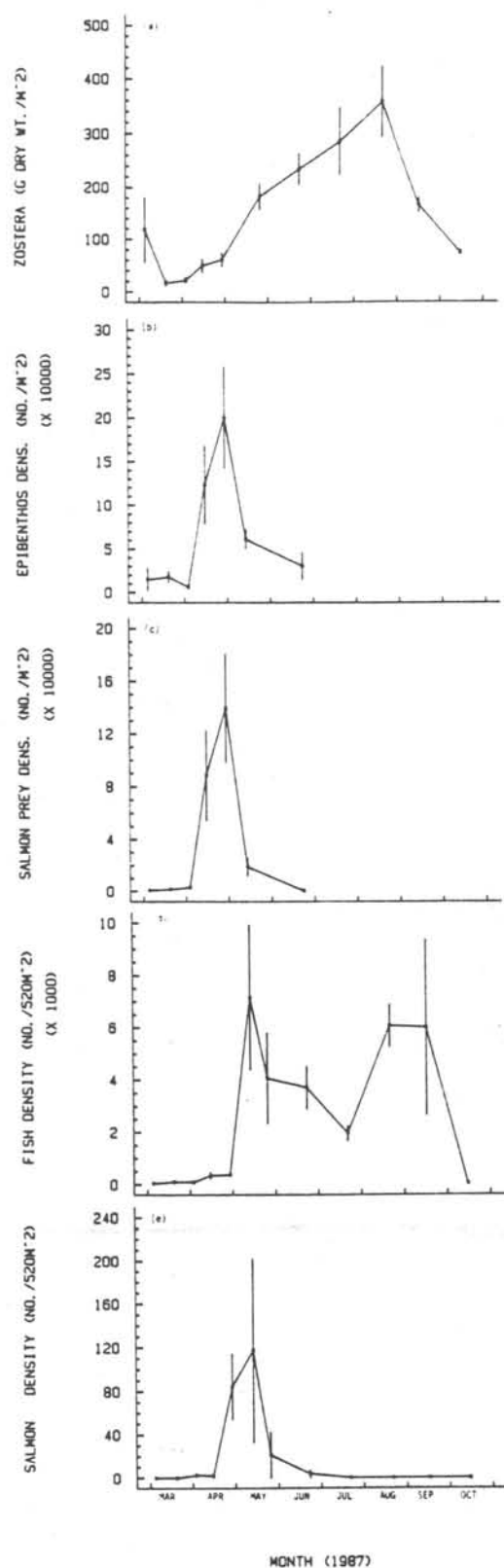


Figure 3. Temporal variations in mean values ( $\pm 1$  SE) of biological parameters in the eelgrass habitat (site EG): (B) *Zostera marina* biomass (n=5); (B) total epibenthic zooplankton density (n=3); (C) salmon prey density (n=3); (D) total fish density per beach seine (n=3, except October n=1); (E) salmonid density per beach seine (n=3, except October n=1).

contained only small infaunal invertebrates and few taxa of importance in the diet of juvenile salmon in the estuary. One of the probable reasons for this difference with the published information on salmon use of emergent marsh habitat (e.g., Levy and Northcote (1982)) is that this marsh had no tidal channels, which would have provided refugia for fish during tidal exposure.

The correspondence in time between change in epibenthic prey resource densities and predator densities was evident in both the mudflat and eelgrass habitats. Juvenile salmon reached maximum densities shortly after maxima of their preferred prey taxa. Furthermore, peaks in total fish and salmon corresponded to declines in total epibenthos and salmon prey densities, suggesting that predation could account for depletion of selected prey populations as illustrated in other Pacific Northwest estuaries (Healy 1979, Simenstad and Salo 1980).

Juvenile salmon showed an earlier increase in density on the mudflat (MF) as compared to the eelgrass bed (EG). The fact that densities of their preferred prey also increased earlier at MF suggests that the aggregation of juvenile salmon may have been a rapid response to the relative availability of preferred prey (Simenstad and Salo 1980).

Vegetation appeared to play two roles in the systems:

Firstly, vegetation is a possible primary energy source. Coincidence between sediment-associated microflora and prey densities on the mudflats suggested that the changes in epibenthos density could be related to fluctuations in algal biomass during spring and early summer. Very few studies have attempted to assess the sources of energy for the epibenthos assemblage. Sibert et al. (1977) have shown that epibenthic harpacticoid copepods selectively preyed upon by juvenile salmon are detritivores. Using stable carbon isotopes, Simenstad and Wissmar (1985) further indicated that harpacticoid copepods and gammarid amphipods consumed by salmon in estuaries are assimilating carbon directly or indirectly from estuarine tideflat primary producers. In addition, it is not surprising that benthic copepods should be feeding on benthic diatoms.

Secondly, vegetation forms refuge. The eelgrass bed harbored a large number of fish species and high crab densities during most of the summer, and their major increases and declines corresponded in time with the increase and decline of *Zostera marina* biomass. Many of the species occupying the bed were represented by juveniles, providing further evidence of the importance of the bed as a refuge for young fish and crabs (e.g., Heck and Thoman 1984, Main 1987). The late summer increase in fish density on the mudflats (MF and CF), which corresponded in time with the presence of massive mats of *Enteromorpha*, also indicates that fish may be utilizing the mats as a refuge in this comparatively featureless habitat.

Assuming that vegetation plays a significant role in the estuarine system, what factors cause the differences in temporal patterns in the vegetation among the habitats?

Firstly, high intertidal mudflats receive more energy (i.e., light and heat) earlier in the season—this is due to the late winter shift of neap tides to daylight times, which promotes increased production rates among benthic microalgae (Admiraal and Peletier 1980). In general, algal production in nearshore systems in Puget Sound appears to be light limited in winter (Strickland 1983, Anderson et al. 1984, Thom et al. 1988a). Rapid increases in light energy in early spring result in rapid increases in algal production and biomass, which are initially dominated by benthic microflora and phytoplankton in Pacific Northwest estuaries (Thom 1978, Anderson et al. 1984, Thom et al. 1984). Hence, the high intertidal mudflats, with a flora having relatively high productivity and turnover rates, show an early spring increase. Eelgrass and other marsh plants, with relatively slower rates of biomass accumulation, show a measurable increase later in the spring. Benthic diatoms show a biomass maximum earlier in spring in Puget Sound as compared to benthic macroalgae (Thom 1978, Thom et al. 1976).

Secondly, the marina flat and slope are protected from most winds, which tend to disturb the development of benthic microalgal and filamentous macroalgal growth typically found in early spring. Amspoker and McIntire (1986) have shown that hydrological disturbance of sediments in the Columbia River estuary resulted in seasonal fluctuations in the sediment-associated microflora. With the onset of summer, winds typically shift to gentle northerlies, and diminished wind disturbance of the CF site allows an increase in the standing stock of the benthic microflora.

Thirdly, although not studied by us, inorganic nutrient concentrations are potentially higher in the marina owing to disposal of wastes from boats. Nutrients reach levels that limited algal growth in summer in Drayton Harbor (Thom et al. 1988, and unpublished data), and increases in nutrient concentrations from anthropogenic sources in the marina during this period could enhance the amount of algal biomass that accumulates on the marina flat.

We conclude that, for a variety of physical and chemical reasons, the marina flat represents a somewhat unique situation in Drayton Harbor with regard to viable foraging habitat for juvenile salmon early in spring. In terms of importance of the habitats studied to fisheries resources, we conclude that the eelgrass habitat is most important, followed by the marina flat (and slope), the unprotected mudflat outside the marina, and the marsh. Destruction of the high mudflat would result in a loss of juvenile salmon feeding habitat important for a short period of time very early in the outmigration season. Replacing this

habitat with eelgrass in the marina would result in enhanced fish prey densities, fish densities, and salmonid and crab densities potentially for a period of time later than, but exceeding in duration, that afforded by the marina flat (Thom et al. 1988b).

Finally, the natural experimental situation presented in Drayton Harbor allowed us to address several questions in terms of: (1) the effects of marina development on estuarine systems; and (2) potential strategies for minimizing the environmental consequences associated with marina development. We suggest that, where conditions permit, scientists should take advantage of such natural experiments for evaluating the environmental impacts of wetland development on estuarine systems. The study design should include: (1) comparisons with carefully selected reference (control) sites; (2) replacement habitat types potentially of use as replacement for the impacted habitat; and (3) sampling of subtle temporal and microhabitat differences among habitats that might affect use by fish and wildlife resources. For example, temporal differences among habitats in occurrence of prey resources and juvenile salmon occur, and these aspects of the habitats must be considered for in-kind replacement mitigation. The real success of replacing the high intertidal mudflat with low intertidal eelgrass partially rests on the ability of eelgrass to assume the early spring prey production role presently carried out by the mudflat.

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