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MITIGATING ROCKY HABITAT LOSS USING ARTIFICIAL REEFS

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ABSTRACT

An artificial reef was constructed on a featureless sand bottom as mitigation for the man-caused loss of rocky-type subtidal habitat in Elliott Bay, Puget Sound, Washington from a shoreline development (fill) project. Using a list of indicator biota developed for this region, it was predicted the mitigation reef would develop a greater number of economically important fish species and greater diversities of sessile and epibenthic biota assemblages than the development site. A total of 181,400 metric tons of quarry rock was used to construct fourteen 41 m · 15 m · 6 m (high) reef structures in a 2.83 ha area during May 1987. This design of a 1:2 ratio of reef material : sand bottom also accommodated the trophic level relationships normally occurring for fishes feeding from reef structures and surrounding natural habitats. The mitigation reef met the predicted development during the reef's first 8 months of submergence. Fish species diversity and densities on the mitigation reef have surpassed that observed on a rocky bottom adjacent to the development site. Some displacement of resident fish appeared to have occurred as evidenced by the greater diversity and density of flounder observed on the adjacent sand bottom compared to those observed on the sand bottom between the mitigation reef structures. Impacts of artificial reefs on benthic organisms were assessed. The density and diversity of benthic organisms decreased significantly under portions of 5- and 7-year-old Puget Sound artificial reefs on cobble and sand habitats.

Mitigation for man-caused habitat degradation is often required by resource agencies in an attempt to obtain the objective of no net-loss of in-kind habitat (USFWS, 1981). Mitigation projects which fail to achieve this objective are often the result of using unproven habitat modification techniques. These failures are usually a manifestation of inadequate site selection and project evaluation studies, which are often based only on qualitative measurements (Steinhart, 1987). This cursory treatment of many mitigation projects occurs because mitigation is often "seen . . . as part of the bargaining process rather than part of the biological challenge of development" (Steinhart, 1987).

Some mitigation projects which fail, attempt to change the community structure in the mitigation habitat through the mass introduction of a desired species. Either the introduced species does not survive because the species is inappropriately placed in environmental conditions detrimental to its survival (Steinhart, 1987), or it is eventually out-competed by a dominant resident species (Carter et al., 1985; Boesch, 1987). Other unsuccessful mitigation projects often result from the introduction of a new habitat in locations which are physically inappropriate, or locations in which the dominant biota are not compatible with the introduced habitat (Bohnsack and Sutherland, 1985).

The placement of rock (artificial reefs) has been extensively documented in the scientific literature as a successful technique for marine fisheries enhancement (Bohnsack and Sutherland, 1985). This successful use of artificial reefs is dependent only on the colonization by a natural succession of organisms which normally occur in natural rocky habitats. However, the application of artificial reefs as mitigation for damaged or lost rocky habitats has not been extensively studied or documented. In recognition that artificial reefs ". . . can enhance the habitat and diversity of fishery resources. . . ." the National Artificial Reef Plan called

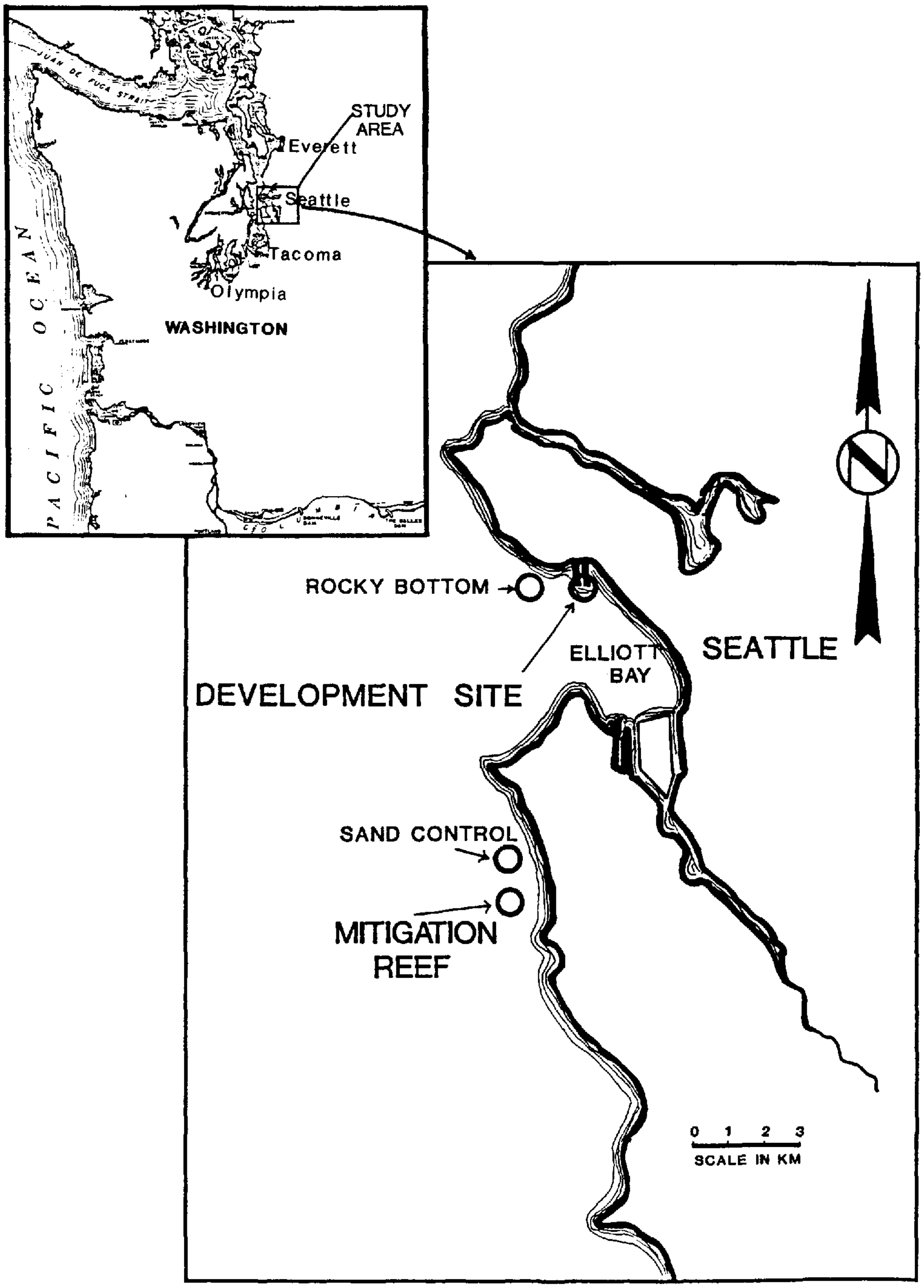

Figure 1. Location of the mitigation reef, development site, rocky bottom, and sand control surveyed for this study in Puget Sound, Washington.

Table 1. Densities (per 100 m^2) of rocky reef fish species observed during SCUBA surveys on three artificial reefs near Olympia (OL), Blake Island (BI), and Whidbey Island (WI), during their first two years of submergence, and the development site prior to filling in Puget Sound, Washington

	Artificial reefs			Development site
	OL N = 7	BI N = 15	WI N = 5	N = 3
Shiner perch (*Cymatogaster aggregata*)	2.9	2.7	1,469.6	8.0
Striped seaperch (*Embiotoca lateralis*)	100.4	9.3	37.7	18.5
Pile perch (*Rhacochilus vacca*)	70.8	3.6	47.0	1.6
Brown rockfish (*Sebastes auriculatus*)	0.7	0.3	0.1	0.5
Copper rockfish (*Sebastes caurinus*)	0.8	2.8	0.8	0.2
Yellowtail rockfish (*Sebastes flavidus*)			0.7	
Quillback rockfish (*Sebastes maliger*)	0.3	0.4	1.9	
Copper/Quillback juvenile rockfish	0.1	<0.1	5.2	0.3
Black rockfish (*Sebastes melanops*)	<0.1		<0.1	
Yelloweye rockfish (*Sebastes rubberimus*)			<0.1	
Kelp greenling (*Hexagrammus decagrammos*)				<0.1
Lingcod (*Ophiodon elongatus*)	1.1	0.1	3.4	
Cabezon (*Scorpaenichthys marmoratus*)	0.1	<0.1	<0.1	
(Total)	(177.2)	(19.2)	(1,566.4)	(29.1)
Total No. of species	9	8	11	6

for more research to determine if artificial reefs can be used as mitigation tools (Stone, 1985).

The purpose of this paper is to demonstrate that artificial reefs can be used to compensate for man-caused losses of rocky habitats in Puget Sound, Washington. Data for this paper were obtained from the Port of Seattle's efforts to mitigate for a shoreline development (fill) project in Elliott Bay by constructing an artificial reef to compensate for approximately 2.83 ha of impacted rocky habitat. The objective of this artificial reef was to develop an assemblage of economically important fish species similar to, or greater than, the impacted habitat.

METHODS AND MATERIALS

Study Locations.—The development site (before filling), a rocky bottom 1,050 m west of the development site, the mitigation reef, and a firm sand bottom 200 m north of the mitigation reef (Fig. 1) were surveyed for this study. The development site consisted of 0.3 m to 1.2 m diameter rip-rap and pier pilings which extended from MHHW to 12.2 m below MLLW. The bottom substrate below 12.2 m consisted of soft sand and mud. The rocky bottom consisted of 0.15 m–1.2 m diameter rocks covering firm sand, and served as a reference for the development site after filling. The mitigation reef was constructed during May 1987 with 181,400 metric tons (mt) of 0.3 m to 1.2 m diameter quarry rock distributed between 14 piles, each covering 615 m^2 of firm sand bottom. The firm sand bottom near the mitigation reef served as a control for the sand habitat prior to the construction of the reef.

Survey Methods.—Biologically acceptable sites for the mitigation reef were located using a list of 29 indicator species developed for this region (Hueckel and Buckley, 1989). SCUBA was used to conduct 30-min random-search surveys for NRI species at the development site and potential mitigation reef sites. SCUBA surveys using the strip transect method (Brock, 1954) documented the occurrence of economically important fish species. An airlift (Benson, 1989) was used to sample epifauna from five 100 cm^2 areas on the hard substrata at the development site (before filling) and the mitigation reef. Infauna were sampled at the sand bottom control site by penetrating fifteen $30.5 \cdot 2.9$ cm diver-held core tubes 15 cm into the substrate. Infauna were also sampled under six $1.2 \cdot 1.5$ m to $1.2 \cdot 2.4$ m concrete slabs at two artificial reefs constructed during 1980 and 1982 off Blake Island (near Seattle) covering cobble, and off Tacoma, covering sandy mud, respectively (Fig. 1). Four different locations around and under the slabs were sampled, including 1 m away, adjacent, inside edge, and center. The

Table 2. Invertebrate species identified in five 100 cm^2 samples collected from the mitigation reef, the OL*, BI*, and WI* artificial reefs, and the development site prior to filling in Puget Sound, Washington during July. (* After 2 years of submergence)

			Artificial reefs		
Invertebrates	Mitigation reef (No. in samples)	Development site (No. in samples)	OL	BI (No. in samples)	WI
Porifera					
Scypha sp.			14		
Platyhelminthes					2
Nemertea					
Nemertean worms:					
Nemertean sp.					4
Annelida					
Polychaete worms:					
Ampharetidae			1		
Cirratulidae					
Ophellidae	5	75			
Nereidae		5			2
Phyllodocidae	1		1	1	6
Polynoidae			50	1	
Sabellariidae			30		
Sabellidae					10
Syllidae	1		8		2
Mollusca					
Chitons:					
Tonicella lineata				1	
Snails and limpets:					
Crepidula nummoris				2	
Crepipatella lingulata			24		
Lacuna variegata				1	
Nassarius mendicus			4		
Notoacmea scutum				1	
Ocenebra interfossa				1	
Odostomia sp.		50	30	1	
Seaslugs:					
Nudibranch sp.			3	2	
Bivalves:					
Clinocardium nuttallii	1				
Chlamys hastata				2	
Chlamys rubida					2
Hiatella gallicana			3		
Macoma sp.		2			
Mytilus edulis			1		12
Musculus sp.		1			
Pododesmus cepio					4
Psephidia lordi					4
Echinodermata					
Eupentacta sp.			1		
Arthropoda					
Pycnogonida				1	
Copepods:					
Calanoida			1		
Harpacticoida			2		
Tanaidacea	1		2		
Barnacles:					
Balanus glandula	111	8			154
Mysids:					
Mysid sp.		2	6		4
Amphipods:					
Caprellidea			5	9	
Gammaridea	2		24	10	

Table 2. Continued

				Artificial reefs	
Invertebrates	Mitigation reef (No. in samples)	Development site (No. in samples)	OL	BI (No. in samples)	WI
Shrimp:					
Crangonidae		3			
Eualus herdmani				3	
Eualus sp.	1				
Lebbeus sp.			1	1	
Spirontocaris sp.				1	2
Crabs:					
Cancer oregonensis			6		26
Hyas lyratus			3	1	2
Pagurus sp.				2	
Pugettia gracilis		1			
Megalops	1				
Chordata					
Sea squirts:					
Ascidia sp.			1		
Boltenia villosa			1		
Chelyosoma columbianum			26		2
Corella willmeriana			6		
Total No. organisms	124	147	254	41	238
Shannon's diversity indices	0.230	0.542	1.124	1.066	0.632

airlift was used to take 15.2 cm diameter · 10 cm deep samples from the cobble, and the core tubes were used to sample the sandy mud. Lift bags were used to move the concrete slabs.

Analysis.—Shannon-Wiener's Diversity indices (Zar, 1984) were used to quantify infauna diversity and the two sample *t*-test was used to test for differences. Analysis of variance (ANOVA) and Duncan Multiple Range Test (Zar, 1984) were used to test for statistical differences between infauna densities.

RESULTS AND DISCUSSION

The strength of a prospective artificial reef site's potential to support economically important fish species is based on the degree of similarity between the Natural Reef Indicator (NRI) species common to productive natural rocky habitats in Puget Sound, and the number of NRI species identified at that site. The NRI species were used to help select a site for the mitigation reef. A site was considered to be biologically acceptable if it was limited in rocky habitat and the number of NRI species identified at that site was equal to, or greater than, the number of NRI species identified at the development site.

Four biologically acceptable sites for the mitigation reef were located. Three of these sites adjacent to the development site were eliminated from consideration due to potential conflicts with existing commerce boat traffic and/or commercial net fisheries. The closest site without fishery conflicts was located 8 km south of the development site (Fig. 1).

A total of 19 NRI species were identified at this site which were associated with a defunct storm drain overflow pipe and other artifacts (tires, bottles, etc.) compared to 9 NRI species identified at the development site (prior to filling). Similar numbers of NRI species were identified at the mitigation reef site and three different rocky habitat limited sites off Olympia (20), Blake Island (18), and Whidbey Island (22) (near Everett) in a separate study (Fig. 1; Hueckel and

Table 3. Average density (per m^2) and diversity indices of infaunal organisms identified from core samples taken from around and under six large concrete blocks following 5 and 6 years of submergence over sandy mud and cobble bottoms in Puget Sound, Washington. (Values connected by a common line are not significantly different at $P = 0.05$)

		Cobble		Sandy mud	
Location from block	Cores (No.)	$\bar{x}$ density (per m^2)	Diversity indices	$\bar{x}$ density (per m^2)	Diversity indices
1 meter	6	7,565	1.320	1,675	1.035
Adjacent	6	7,061	1.347	2,297	0.981
Inside edge	6	2,774	1.361	811	0.856
Center	3	504	0.999	570	0.477

Buckley, 1989). Surveys of artificial reefs subsequently constructed at these three sites, during the first 2 years of submergence, identified from 1.5 to 1.8 times the number of economically important fish species (Table 1), and significantly ($P = 0.05$, $t = 50.1$, 30.2, and 6.4, respectively) greater diversities of sessile and epibenthic biota assemblages as the development site prior to filling (Table 2). From this information, it was predicted the mitigation reef would develop similar biota assemblages and diversities as these three artificial reefs.

While the mitigation reef site was relatively free of commerce conflicts, the impact to the sand bottom habitat from the reef had to be considered to insure impacts would not outweigh the benefits of future reef production. Few scientific studies have examined the effects of artificial reefs on biota inhabiting the surrounding open bottom (Bohnsack and Sutherland, 1985). Most artificial reefs are rapidly colonized by adult fish, which presumably originated on nearby natural reefs (Bohnsack and Sutherland, 1985; Mathews, 1985), but the long-term effects on the natural reefs is still unknown. Fish, other epifauna, and infauna in the nonreef habitats surrounding artificial reefs have been reported to be unaffected (Walton, 1982; Davis et al., 1982).

The open bottom habitat which surrounds artificial reefs is known to supply food items for some reef fishes (Hueckel and Stayton, 1982). Energy is transferred from this habitat to the reef when open bottom habitat fish and invertebrates are consumed by reef fishes, and through reef dwelling detritivours consuming feces deposited by open bottom foraging reef fishes (Bray and Miller, 1985; Hueckel and Buckley, 1987). The interface between the reef and surrounding open bottom has also been shown to be important to some key reef fishes (Wilson and Krenn, 1986). Based on this research, the open bottom around artificial reefs is considered to be of equal importance to the reef community as the reef itself.

The concrete slabs placed over the sandy mud, and cobble bottoms at the existing artificial reefs had a negative effect on the infauna. The density and diversity of infauna decreased significantly ($P = 0.05$, see Table 3) from around, and under, the three slabs at each reef location. The slabs had a greater negative effect on the infauna inhabiting the cobble than the sandy mud. The density of infauna decreased 15 times from the surrounding area to the slab center on the cobble bottom compared to a three-fold decrease on the sandy mud.

The open sand bottom at the mitigation reef site supports a diverse assemblage of infaunal organisms (Table 4) many of which have been shown to be important prey items for some reef fishes (Hueckel and Buckley, 1987). The commercially important geoduck clam (*Panope generosa*) were also present in the reef area.

Table 4. Total number of organisms collected in 15 30.5·2.9 cm core samples taken between 12.2 m to 18.3 m at the mitigation reef site during March 1987 prior to reef construction

Organism	Organisms (No.)	Samples containing species (No.)	Per m^2 (No.)
Annelida			
Capitellidae	1	1	114
Chaetopteridae	3	3	341
Glyceridae	2	2	227
Goniadidae	1	1	114
Hesionidae	1	1	114
Maldanidae	3	2	341
Magelonidae	1	1	114
Nereidae	1	1	114
Nephtyidae	1	1	114
Oligochaeta	1	1	114
Phyllodocidae	1	1	114
Spionidae	4	3	455
Terebellidae	1	1	114
Trichobranchidae	1	1	114
Nemertina	1	1	114
Mollusca			
Snails:			
Bittium eschrichtii	1	1	114
Clams:			
Axinopsida sericata	2	2	227
*Panope generosa**			1.7
Psephidia lordi	1	1	114
Veneridae	1	1	114
Arthropoda			
Amphipods:			
Gammaridea	4	4	455
Sipuncula			
Golfingia sp.	1	1	114

* *Panope generosa* (Geoduck clams) were quantified using three 100 m·2 m strip transects through the mitigation reef site.

The 15.2 m spacing between reef structures at the mitigation site provided natural open benthic foraging areas between structures. This spacing also maintained continuity of the reef fish community and the trophic level relationships normally occurring for fishes feeding from between the reef structures and surrounding natural habitats. The 1:2, reef: sand bottom ratio minimized the overcovering of geoducks and other infauna in the reef area. This ratio of reef: sand bottom did not alter the colonization of economically important fish species to other Puget Sound artificial reef structures (Buckley and Hueckel, 1985).

Mitigation should be viable for as long as the habitat subject to the mitigation is impacted. These impacts are often permanent. Therefore, artificial reefs used for mitigation should be constructed with non-deteriorating materials which are suitable for the development of a living natural reef community. Artificial reefs which have been constructed from materials which deteriorate in water have developed viable natural reef communities (Bohnsack and Sutherland, 1985), but the limited life spans of the base materials are detrimental to the reef communities (Turner et al., 1969). Continued replenishment of these types of materials may not provide for adequate mitigation, as the reef community would be in a constant

Table 5. Average densities of fish species (per 100 m^2) on the mitigation reef, sand control, and rocky bottom from June 1987 through February 1988

Fish	Mitigation reef (N = 7)	Rocky bottom (N = 7)	Sand control (N = 7)
Shiner perch	209.2	4.0	
Striped seaperch	87.7	5.8	
Pile perch	38.0	0.3	
Surfperch (total)	(334.9)	(10.1)	
Brown rockfish	0.3		
Copper rockfish	2.6	0.1	
Quillback rockfish	14.5	10.1	
Juvenile rockfish	1.0		
Rockfish (total)	(8.4)	(0.2)	
Lingcod	0.1		
Cabezon	0.5		
Rock sole (*Lepidopsetta bilineata*)	0.2	0.2	1.4
Speckled sanddab (*Citharichthys stigmaeus*)			0.3
C-O sole (*Pleuronichthys coenosus*)			0.3
English sole (*Parophrys vetulus*)			0.6
Flounder sp. (Pleuronectidae)	0.2		2.5
Flounder (total)	(0.4)	(0.2)	(5.1)
Total fish	344.3	10.5	5.1

state of early successional development, and would thus fail to replicate the habitat subject to mitigation.

Quarry rock was used to construct the mitigation reef because this material meets the positive factors required for long-term mitigation of rocky habitats, and it is available in large quantities. The stacking of this material during construction, and the use of different sized rocks, creates the diverse crevice habitat necessary for the attraction and survival of many reef-associated organisms (Hueckel and Buckley, 1987).

The mitigation reef has met the objective of developing a similar assemblage of economically important fish species as the development site, prior to its filling, during the reef's first 8 months of submergence (Table 5). Fish species diversity and densities on the mitigation reef has surpassed that observed on the rocky bottom adjacent to the development site. Some displacement of resident fish appeared to have occurred, as evidenced by the greater diversity and number of flounder species observed on the adjacent sand bottom compared to those observed on the sand bottom between the mitigation reef structures (Table 5).

The mitigation reef is undergoing similar successional development as other productive artificial reefs in Puget Sound. The number of economically important fish species which colonized the mitigation reef is similar to those which colonized the three Puget Sound artificial reefs constructed at sites with similar numbers of NRI species as the mitigation reef site (Fig. 2). The domination of the reef surfaces by barnacles (Table 2), and the subsequent grazing by starfish (*Evasterias troschelii* and *Pycnopodia helianthoides*), is a precursor to the development of turf algae and increased densities and diversities of fish prey items and fish species (Hueckel and Buckley, 1987). It can be expected that the mitigation reef will be colonized by additional fish species as this successional process continues.

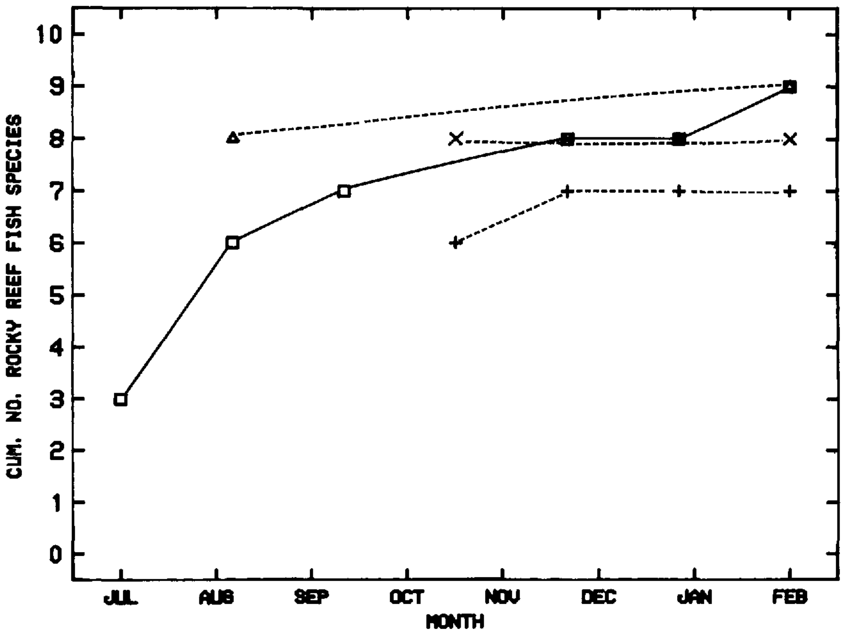

Figure 2. The number of economically important rocky reef fish species observed on the mitigation reef (—□—), and the artificial reefs off Olympia (-×-), Blake Island (-+-), and Whidbey Island (-△-) during their first year of submersion.

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