BULLETIN OF MARINE SCIENCE, 62(2): 389–408, 1998

RECRUITMENT PATTERNS OF CULTURED JUVENILE PACIFIC THREADFIN, *POLYDACTYLUS SEXFILIS* (POLYNEMIDAE), RELEASED ALONG SANDY MARINE SHORES IN HAWAII

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ABSTRACT

Release-recapture studies were conducted with Pacific threadfin, *Polydactylus sexfilis*, the species given highest priority for stock-enhancement research in Hawaii. Their purpose was to evaluate recruitment potential, dispersal, growth, and differential recapture rates of cultured fingerlings released into shoreline juvenile nursery habitats along the windward (eastern) coast of Oahu, Hawaii. We varied fish size at release, release site, and the seasonal timing of releases using a balanced, randomized-block experimental design. After releases of 20,000 tagged Pacific threadfin in 1993 and about 81,000 in 1994, we recaptured 1705 cultured juveniles in net collections made over a 17-mo period. Presence of cultured fish in net samples depended strongly on the interactive effects of release variables. Size at release had an important effect on recapture rates at all release sites, but this effect varied seasonally. At one of the release sites, larger fish apparently had better survival after winter releases and smaller fish had better survival after summer and fall releases. Release site affected dispersal patterns, recruitment, and recapture rates. The percentage of cultured fish in samples of Pacific threadfin taken 8 mo after release varied from 0% to 64%. Cultured fish showed strong site fidelity at some sites, weak at others. What we considered "pilot"-scale releases clearly were large enough to approach swamping wild recruitment at Kahana Bay. A key question from this study is how many cultured juvenile Pacific threadfin the Kahana Bay site can support without displacement of wild individuals.

Worldwide declines in coastal fishery landings (FAO, 1994) have prompted a resurgence of interest in evaluating the potential of hatchery-based marine stock enhancement (release of cultured juveniles to increase abundance of wild stocks that spawn in seawater) as a tool to help replenish depleted fisheries (see symposium proceedings edited by Lockwood, 1991; Danielssen et al., 1994; and Schramm and Piper, 1995). Recent studies indicate that released cultured organisms can make substantial contributions to fishery landings of some coastal stocks (e.g., Kitada et al., 1992; Honma, 1993; Leber and Arce, 1996). Because of increased marine stocking, more information is needed for evaluation of the desirability and effectiveness of such releases (Peterman, 1991; Cowx, 1994; Blankenship and Leber, 1995; Munro and Bell, 1997).

Release-recapture studies in Hawaii are evaluating hatchery-release effects on marine and estuarine species with different trophic and habitat preferences. In 1988, Pacific threadfin, *Polydactylus sexfilis* (Polynemidae), was given the highest research priority in Hawaii among species evaluated for studies to examine the potential of marine stock enhancement as an additional fishery-management tool (Leber, 1994). The species is a marine carnivore. Juveniles prefer inshore, sandy marine habitats. Adults feed in sandy patches among reefs and in the surf zone along Hawaii's sandy and rocky shores. Pacific threadfin is a very popular sport fish that also supports a small subsistence fishery in Hawaii. Historically, this species was prized by the kings of Hawaii, who built saltwater fish ponds to grow wild juveniles for food. During this century, Pacific threadfin have declined

Table 1. Summary statistics for 20,010 fish tagged and released in 1993 for evaluation of hatchery releases in Kahana Bay and at Laie Beach. Unique batch codes were used to identify fish from each cell in the matrix. Lot 1 was released on 2 November, lot 2 on 16 November, and lot 3 on 7 December. All released fish were marked with coded-wire tags placed in the snout and visible implant elastomers within the adipose eyelid tissue.

		Release lots			
Release site	Size at release	1	2	3	Total
Kahana Bay	70–100 mm	970	1,562	1,737	4,269
	100–130 mm	1,400	1,758	1,416	4,574
	130–150 mm	258	489	430	1,177
	Subtotal	2,628	3,809	3,583	10,020
Laie Beach	70–100 mm	935	1,602	1,764	4,301
	100–130 mm	1,307	1,740	1,446	4,493
	130–150 mm	375	411	410	1,196
	Subtotal	2,617	3,753	3,620	9,990
Grand total		5,245	7,562	7,203	20,010

severely in abundance in Hawaii, especially on the island of Oahu, where many inshore fish populations have been depleted (Shomura, 1987).

The first step required in evaluating stock-enhancement potential of the Pacific threadfin was to develop aquaculture production technology, and progress has now been made in that area (Kelley et al., 1995; Ostrowski et al., 1996). The next step, presented here, was to conduct pilot release-recapture experiments to evaluate release strategies and recruitment potential of cultured Pacific threadfin. This study was conducted at nursery habitats along the windward (eastern) coast of Oahu. Differences in recapture rate of released fish were a function of release size, season, and site. This pilot study had a major effect on juvenile recruitment at one of the study sites.

Materials and Methods

Culture of Pacific Threadfin.—We spawned wild Pacific threadfin brood stock at The Oceanic Institute to produce fingerlings for release into the wild. Batches of eggs were hatched every 10 d over a 3-mo period in 1993 and over a 5-mo period in 1994. At least 30 wild females were spawned. Larvae from each batch were hatched and reared for 25 d in 4000-L raceways or 5000-L cylindrical tanks according to protocols described by Ostrowski et al. (1996). We size graded postlarvae (25 d old, 10–20 mm fork length [FL]) with a commercial bar grader to separate fish greater than and less than 15 mm FL to reduce cannibalism. Fish were then transferred to 8000-L cylindrical tanks and reared for 15 d to stage-one juveniles (30–60 mm FL, 40 d old). Stage-one juveniles were size graded and then transferred to 20,000-L cylindrical tanks and reared for 15 d to stage-two juveniles (50–80 mm FL, 55 d old). Stage-two juveniles were size graded and split into additional 20,000-L tanks, where they were reared to the sizes released (fingerlings 48–150 mm FL).

Initial Release-recapture Experiment: Effect of Release Site and Size at Release.—In 1993, a release-recapture experiment yielded preliminary data on the effects of release site and size at release (SAR) on growth and recapture rate. Three sizes and two release locations were used, and the releases were repeated three times from 2 November through 8 December, during peak juvenile recruitment season. All fish were individually tagged with both coded-wire tags and visible implant tags (Northwest Marine Technology, Inc.) that identified experimental treatment conditions. Fish were released at two sites along Oahu's northeastern coast, half at Kahana Bay and the other half at

Laie Beach (Fig. 1). Within SAR groups, replicate release lots contained roughly equal numbers of fish (Table 1).

Fish were harvested from culture tanks and transferred to 40,000-L holding tanks for tagging. During harvesting, fingerlings were crowded together with connected, mesh-panel crowders, which minimized handling of the sensitive juveniles. Crowded fish were then scooped out of the water with 15-L buckets and "wet-packed" to a transport tank. Salinity in the transport tank ranged between 25 and 28‰, which improved transfer recovery. Salinities in the nursery and holding tanks normally fluctuated between 32 and 34‰. During tagging, fish were held in floating 4-ft × 8-ft net pens that separated fish sources and size classes. Time between sorting and tagging ranged from 1 to 8 d depending on the condition of the fish and the tagging schedule.

Binary-coded-wire tags (CWT, Jefferts et al., 1963) were implanted in the snout area by an automatic injector with head molds designed and developed specifically for juvenile Pacific threadfin by Washington Department of Fish and Wildlife biologists Lee Blankenship and Dan Thompson. Size-specific head molds ensured accurate CWT placement and resulted in a tagging speed of about 1000 fish hr^{-1} per injector. Unique codes were used for each release site, release lot (date), and SAR. Fish were tagged in batches, with a different code for each site-SAR-lot combination (2 × 3 × 3 = 18 batch codes). Fish released in 1993 were divided into three size intervals: 70–100 mm, 100–130 mm, and 130–150 mm FL. (Note below that smaller fish were released in 1994: 48–70 mm, 70–100 mm, and 100–130 mm FL). The principal difference between fish in the different size intervals was age. All fish were released between 08:00 and 13:00 at release sites with bottom salinities between 30 and 35‰.

In addition to coded-wire tags, all fish released in 1993 and half those released in every treatment group in 1994 were also tagged with visible implant elastomers (Godin et al., 1995; Frederick, 1997), which externally marked fish with internal CWTs. The data for the visible tags will be reported elsewhere (Blankenship and Leber, unpubl. data).

Follow-up Release-recapture Experiment: Interaction of the Timing of Releases with SAR and Release Site.—In 1994, to assess a different release site and to evaluate interactive effects of release strategies on recapture rate, we released 81,225 fish. The balanced, factorial, randomized-block design included two sites, three SARs, three seasons, and three lots (2 × 3 × 3 × 3 = 54 batch codes). The principal difference between the 1993 and 1994 experiments was the addition of release season as an experimental variable in 1994. Releases occurred at various times before and during the peak juvenile recruitment period — three during July–August ("summer"), three in September–October ("fall"), and three in November–December ("winter") (Table 2). Smaller individuals were released in 1994 (48–130 mm FL) than in 1993 (70–150 mm FL). Juveniles were size graded into three groups, tagged with both coded-wire tags and visible implant tags, and released. Releases were at Kahana Bay and Malaekahana Bay (Fig. 1). Fingerlings were harvested and tagged as described above. During both years, releases at the two sites were <1 h apart.

To verify tag-retention rates for this study, we examined a random subsample of at least 5% of the fish tagged for each SAR group within release lots before each release (fish in the subsample were in addition to the 81,225 fish actually released). The subsamples were placed in 1000-L cylindrical tanks and held for 8 mo. Tag retention was monitored monthly. Fish in the subsamples were not released.

All three release sites were juvenile Pacific threadfin habitats with sandy bottom and moderate wave energy. Kahana Bay is unique in receiving more freshwater inflow than the other two sites. Salinities in the bay were generally high (>30‰) but fluctuated between 10 and 32‰ during rainy periods. Releases at Kahana Bay were performed at a boat ramp with a release hose 30 ft long and 4 in in diameter.

Laie Beach (approximately 12 km north of Kahana Bay) does not receive inflow from freshwater streams, and salinities ranged from 32 to 35‰. The Laie release site was located along an unprotected shoreline with coral reefs patchily distributed 3–7 m beyond the sandy beach. Channels among reef patches lead out to a fringing reef 1–2 km offshore. Releases into shoreline water at Laie were performed with a hose 80 ft long and 4 in in diameter.

Table 2. Summary statistics for 81,225 fish tagged and released in 1994 for evaluation of hatchery releases in Kahana Bay and Malaekahana Bay. Unique batch codes were used to identify fish from each cell in the matrix. Summer lot 1 was released on 13 July, lot 2 on 27 July, and lot 3 on 10 August. Fall lot 1 was released on 7 September, lot 2 on 21 September, and lot 3 on 6 October. Winter lot 1 was released on 3 November, lot 2 on 17 November, and lot 3 on 1 December.

		Summer release lot				Fall release lot				Winter release lot				
Release site	Size at release	1	2	3	Total	1	2	3	Total	1	2	3	Total	Grand total
Kahana Bay	48–70 mm	985	1,494	1,283	3,762	1,211	2,069	1,779	5,059	1,225	1,879	1,237	4,341	13,162
	70–100 mm	1,117	1,886	1,111	4,114	2,926	2,083	1,804	6,813	1,967	1,234	1,136	4,337	15,264
	100–130 mm	1,726	1,481	714	3,921	957	908	1,917	3,782	2,863	646	892	4,401	12,104
	Subtotal	3,828	4,861	3,108	11,797	5,094	5,060	5,500	15,654	6,055	3,759	3,265	13,079	40,530
Malaekahana Bay	48–70 mm	855	1,478	1,203	3,536	1,215	2,084	1,786	5,085	1,242	2,160	1,292	4,694	13,315
	70–100 mm	1,218	1,874	713	3,805	2,889	2,078	1,772	6,739	2,024	1,264	1,176	4,464	15,008
	100–130 mm	2,104	1,477	728	4,309	586	974	2,000	3,560	2,840	749	914	4,503	12,372
	Subtotal	4,177	4,829	2,644	11,650	4,690	5,136	5,558	15,384	6,106	4,173	3,382	13,661	40,695
Grand total		8,005	9,690	5,752	23,447	9,784	10,196	11,058	31,038	12,161	7,932	6,647	26,740	81,225

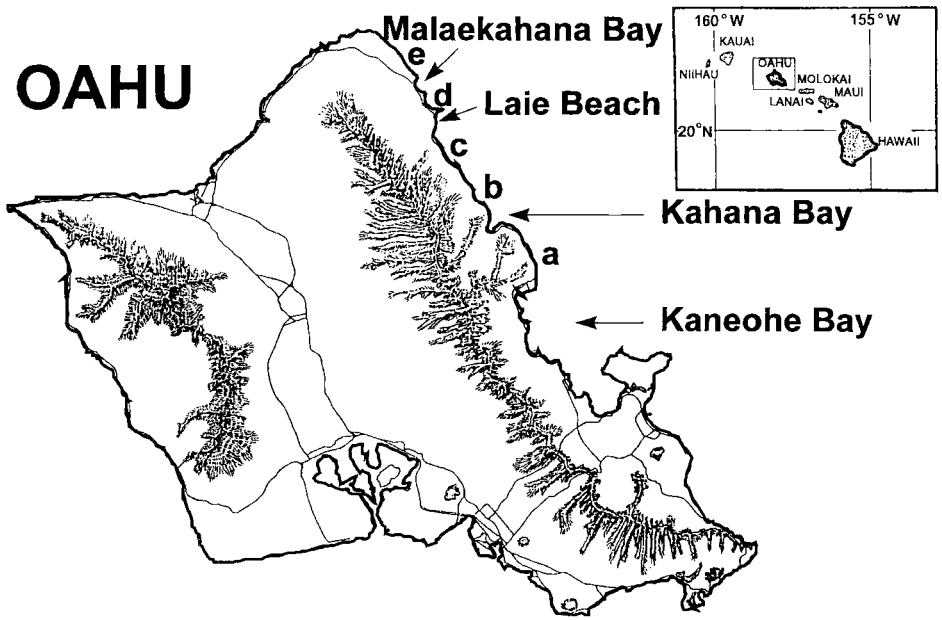

Figure 1. Map of windward coast of Oahu, Hawaii, showing pilot release sites. In this study, periodic seine collections were conducted at the three release sites and five other coastal nursery habitats (a = Kaaawa Beach; b = Punaluu Beach; c = Pounders Beach; d = Hukilau Beach; e = Kahuku Beach). Pacific threadfin releases were made at Kahana Bay, Laie Beach, and Malaekahana Bay. Kaneohe Bay was the principal release habitat on Oahu in previous release-recapture studies of cultured striped mullet.

The northern site, Malaekahana bay, was chosen to replace Laie Beach for the follow-up experiment because of poor recapture rates at Laie. Salinities were typically >32‰. Releases at Malaekahana were performed from a 2-m-high rocky cliff, from which the 80-ft hose extended down onto the beach. At all sites, releases were made into shoreline water 0.5–1 m deep. The distal end of the release hose was pointed at about a 45° angle to the surface of the water, so that fish exited the hose in air and could dive into the water.

RECAPTURE OF TAGGED JUVENILES.—Cultured and wild Pacific threadfin were monitored in periodic seine collections from January 1994 through May 1995. Collections were made during an 8-h daylight period at five sites after 1994 releases and at seven sites after 1993 releases (Fig. 1). Stations were established in the vicinity of Pacific threadfin nursery habitats at various locations along the northeast coast of Oahu.

For seining we used a 25-m-long beach seine, 1.8 m deep, with 1.3-cm stretch mesh and a collection bag 1.8 × 1.8 × 1.8 m. Twelve replicate seine hauls were conducted at each sampling station, because preliminary sampling indicated that that level of effort would produce abundance estimates with a coefficient of variation of <10%. Distribution of seine hauls along the beach was determined by the topography of each site. Seine hauls began seaward of the surf impact zone; seines were pulled through the surf toward the beach. Each seine haul was conducted by at least three researchers — one on each of the wings and a third keeping the central collection bag close to the substratum. Because at two sites the beach was not long enough for 12 non-overlapping seine hauls, we used two substations at each of them (Kaaawa Beach and nearby Kaoio Point formed the "Kaaawa Beach" station; Pounders Beach and nearby Mahakea Beach formed the "Pounders Beach" site). Six seine hauls were made at each of the two substations. At the other stations, the area

Table 3. Retention of coded-wire tags (CWT) after eight months in 3753 Pacific threadfin held in 5000-L tanks. Fish were subsamples from release batches selected randomly on the day of release.

Size interval		Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Lot 6	Lot 7	Lot 8	Lot 9	Totals
48–70 mm	Total fish	106	158	114	127	186	207	197	205	78	1,378
	Total CWT	94	150	110	126	183	184	186	157	76	1,266
	% tag retention	88.7	94.9	96.5	99.2	98.4	88.9	94.4	76.6	97.4	91.9
70–100 mm	Total fish	149	124	72	157	102	198	179	95	110	1,186
	Total CWT	146	119	57	154	99	190	162	74	86	1,087
	% tag retention	98.0	96.0	79.2	98.1	97.1	96.0	90.5	77.9	78.2	91.7
100–130 mm	Total fish	140	40	92	200	97	173	273	72	102	1,189
	Total CWT	126	35	84	199	91	163	256	71	93	1,118
	% tag retention	90.0	87.5	91.3	99.5	93.8	94.2	93.8	98.6	91.2	94.0

Table 4. Numbers of wild and tagged cultured Pacific threadfin recaptured in seine samples collected along the windward coast of Oahu in 1994 and 1995. Forty-nine of the 1705 cultured fish recaptured were released in November and December 1993; 48 of those were recaptured during January–June 1994. The 1994 experimental releases began in July 1994. Twelve seine hauls were made at each collection site. Sampling was discontinued at some sites after 1994 releases when recapture rate was consistently zero.

		1994								1995					
Collection site	Source	Jan	Feb	Mar	May	Jun	Aug	Oct	Dec	Jan	Feb	Mar	Apr	May	Totals
Kahuku Beach	Wild					5	0	4	0	1	27				37
	Cultured					0	0	0	0	0	0				0
	% cultured	–	–	–	–	0	0	0	0	0	0	–	–	–	0
Malaekahana Bay	Wild	0	0	76	73	5	2	6	36	21	23	24	14	14	294
	Cultured	0	0	2	1	1	132	159	217	16	19	3	2	2	554
	% cultured	0	0	2.6	1.4	16.7	98.5	96.4	85.8	43.2	45.2	11.1	12.5	12.5	65.3
Hukilau Beach	Wild	141	189	7	26	2									365
	Cultured	3	0	0	0	0									3
	% cultured	2.1	0	0	0	0	–	–	–	–	–	–	–	–	0.8
Laie Beach	Wild	36	69	13	12	2									132
	Cultured	1	0	0	0	0									1
	% cultured	2.7	0	0	0	0	–	–	–	–	–	–	–	–	0.8
Pounders +	Wild	16	20	5	2	13	2	9	62	9	11				149
Mahakea Beach	Cultured	4	0	0	0	1	3	0	2	0	0				10
	% cultured	20.0	0	0	0	7.1	60.0	0	3.1	0	0	–	–	–	6.3
Punaluu Beach	Wild	120	76	26	15	12	4	1	32	41	72	17	7	0	423
	Cultured	2	0	1	0	0	1	2	16	2	48	3	0	0	75
	% cultured	1.6	0	3.7	0	0	20.0	66.7	33.3	4.6	40.0	15.0	0	0	15.1
Kahana Bay	Wild	131	208	4	55	53	8	3	64	23	29	69	4	43	694
	Cultured	10	6	2	3	1	191	183	284	102	79	82	8	71	1,022
	% cultured	7.1	2.8	33.3	5.2	1.8	96.0	98.4	81.6	81.6	73.2	54.3	66.7	62.3	59.6
Kaaawa +	Wild	175	88	63	41	14	9	11	4	43	17	6	5	0	476
Kaoio Point	Cultured	3	2	2	3	0	1	8	1	11	9	0	0	0	40
	% cultured	1.7	2.2	3.1	6.8	0	10.0	42.1	20.0	20.4	34.6	0	0	0	7.8
Total	Wild	619	650	194	224	106	25	34	198	138	179	116	30	57	2,570
	Cultured	23	8	7	7	3	328	352	520	131	155	88	10	73	1,705
	% cultured	3.6	1.2	3.5	3.0	2.8	92.9	91.2	72.4	48.7	46.4	43.1	25.0	56.2	39.9

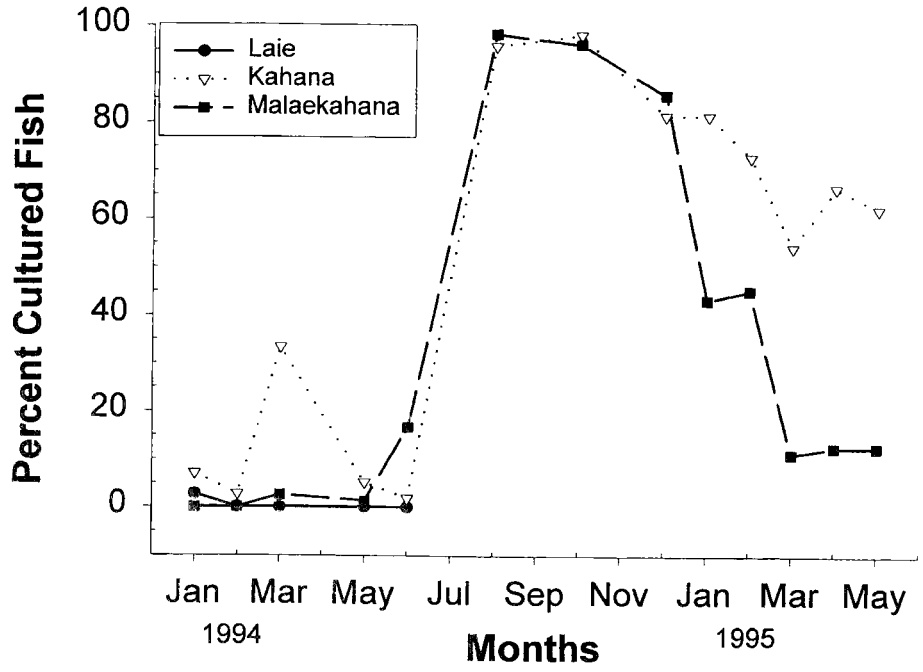

Figure 2. Percent contribution of cultured fish to Pacific threadfin abundance in seine collections. Data are percent cultured fish in Pacific threadfin collections of wild and cultured individuals at each of the three release sites. Releases began in November 1993. 1994 releases began in July and were repeated in September and November. No releases were made at Malaekahana Bay in 1993 or at Laie Beach in 1994.

sampled by the 12 seines ranged from approximately 20% (at Kahana Bay) to 60% (at Malaekahana Bay) of the shoreline.

Pacific threadfin in these collections were measured and checked for tags with a portable tag detector (Northwest Marine Technology, Inc.). Wild fish were counted, measured, and released at the sampling site. We reduced stress to wild fish by keeping them in seawater in 200-L, plastic barrels during collections. Dissolved oxygen was maintained in the barrels by air diffusers connected to oxygen canisters. All tagged fish were measured in the field and returned to the laboratory on ice for tag analysis. After extraction, the binary codes were read with a binocular microscope (40×). All tag codes were verified with a second (blind) reading by another technician.

Data were analyzed with SYSTAT software (Wilkinson, 1990). A randomized-block design ANOVA was used to compare means. Treatments (release site, SAR) were blocked over time (three release lots) within release seasons. Proportions were arcsine transformed. Orthogonal contrasts were used to compare means (Sokal and Rohlf, 1981). SYSTAT Basic was used to write tag-decoding algorithms. Variance estimates are expressed throughout as standard errors.

Results

Over the 17-mo study period, 1705 tagged Pacific threadfin were recovered in seine samples. About 2.5% (43) of the CWTs from these fish were lost during the extraction

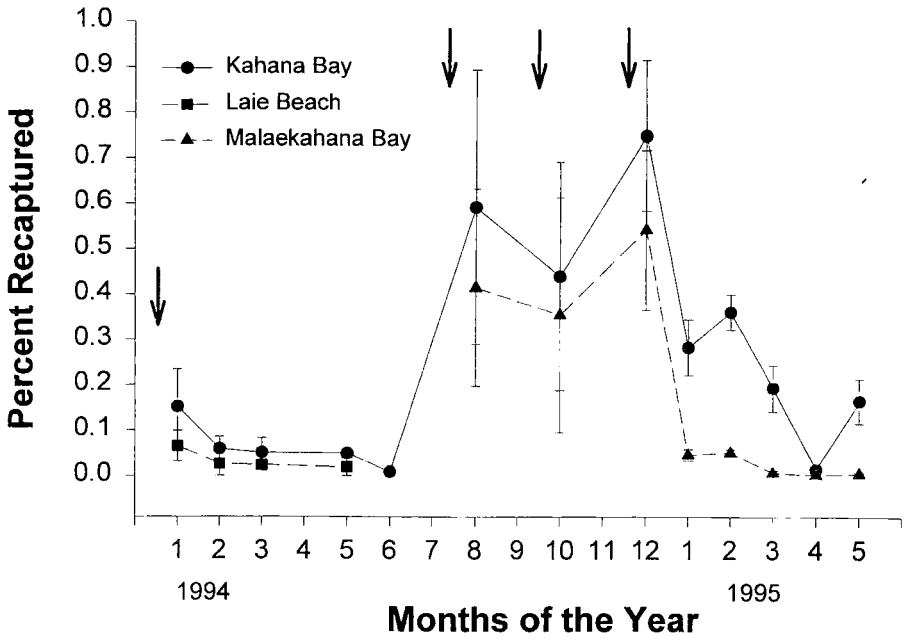

Figure 3. Release-site effect on recapture rate in seine hauls (data = (number recaptured/number released) × 100% ± SEM; n = 3 release lots). Arrows indicate release periods. No releases were made at Malaekahana Bay in 1993 or at Laie Beach in 1994. Numbers on the x-axis represent months of the year.

process. Thus, 1662 CWTs were decoded and analyzed. Of these, 46 tags were from the 1993 releases, and 1616 were from fish released in 1994. All but one of the 46 fish recovered from the 1993 release experiment were captured before the 1994 releases, which began in July.

TAG RETENTION.—During 1993 releases, 1020 cultured Pacific threadfin (in addition to the 20,010 fish released) were retained at The Oceanic Institute for monitoring of tag retention. Tag checks were performed for 8 mo after the release. Mean retention rate was 98.3%. No significant tag loss was observed in any treatment group. The 100–130-mm size class showed initial retention rates of 100%, which stabilized at 97.4% within 8 mo. This is a normal tag loss rate for CWTs (Blankenship, 1990). The 130–150-mm group had initial and final CWT retention of 100%.

In the 1994 experiment, 3753 tagged fish were retained to monitor tag retention. CWT retention was not as high in 1994; it averaged >94.0% for the largest fish released (100–130 mm), and >91.0% for the other two size groups. CWT retention ranged from 76.6 to 99.5% (Table 3).

RELEASE CONTRIBUTION TO ABUNDANCE.—This pilot release study made an unexpectedly large contribution to juvenile abundance at one of the three release sites. Cultured fish comprised less than 1% of the Pacific threadfin collected at Laie Beach, which was subsequently excluded as a release site in 1994 (Table 4). Nine months after the 1994 releases began, the percent contribution of cultured fish to juvenile recruitment remained

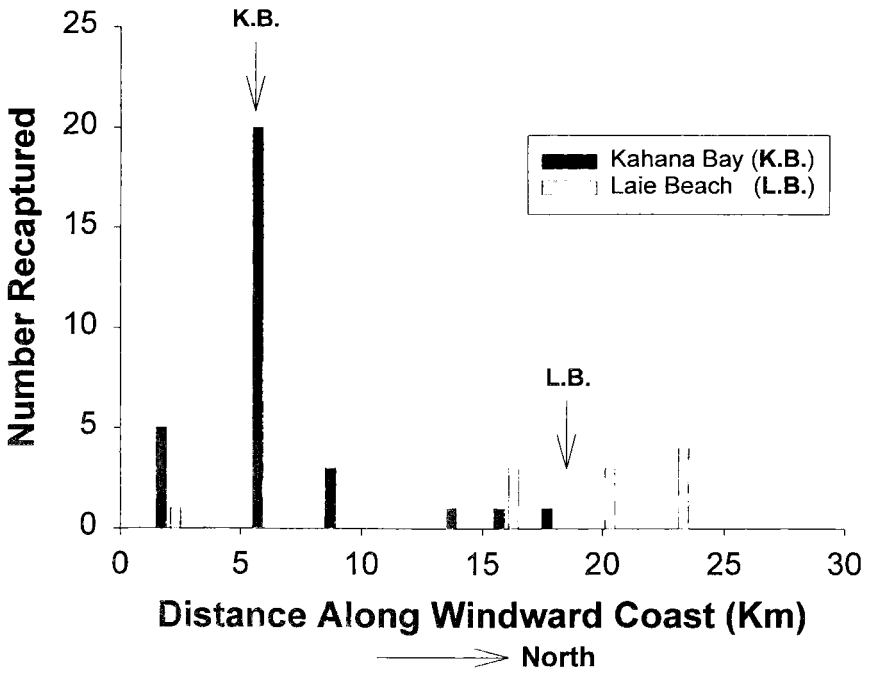

Figure 4. Dispersal after 1993 pilot release experiment. Data are numbers of Pacific threadfin recaptured during the 6-mo period following releases in 1993 at Kahana Bay (solid bars) and Laie Beach (shaded bars). The x-axis is shoreline kilometers north of Kaneohe Bay on the windward (eastern) coast of Oahu. Kahana Bay (K.B.) is approximately 6 km, and Laie Beach (L.B.) approximately 18 km, north of Kaneohe Bay.

substantial at Kahana Bay (>60%) but significantly lower at Malaekahana Bay (Fig. 2; ANOVA, $P < 0.005$ on each of the last five collection dates). Recapture rates (number recaptured/number released) were also greater at Kahana Bay than at Malaekahana Bay (Fig. 3; ANOVA, $P < 0.01$ in January, February, March, and May).

Release site affected dispersal. No fish recovered from the 1993 Laie Beach release was recaptured at the release site (Fig. 4). In contrast, a large proportion of the fish recovered from Kahana Bay and Malaekahana Bay releases were in collections made at the release sites (Figs. 4,5). Only 4% of 1079 fish recaptured after 1994 releases at Kahana Bay had moved to other sites along the coast. Only 0.5% of 537 fish recaptured after their release at Malaekahana Bay had dispersed to other collection sites.

SAR Effect on Recapture Rate.—The initial experiment, started in fall 1993, revealed a significant effect of SAR on recapture rate of cultured Pacific threadfin (Fig. 6; ANOVA, $P < 0.024$). At Kahana Bay, recapture rate was directly proportional to SAR. SAR effect was not examined for the Laie Beach releases because of the small number (12) of cultured fish recovered.

The follow-up experiment, which was repeated in summer, fall, and winter 1994 to replicate the 1993 releases and determine effects of the timing of releases, also revealed