Impact of hatchery releases on the recreational fishery for Pacific threadfin (*Polydactylus sexfilis*) in Hawaii

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Abstract—The Pacific threadfin (*Polydactylus sexfilis*) is considered one of the premier Hawaiian food fishes but even with catch limits, seasonal closures, and size limits, catches have declined dramatically since the 1960s. It was identified as the top candidate species for stock enhancement in Hawaii, based on the decline in stocks, high market value, and importance of the fishery.

In the stock enhancement program for Pacific threadfin, over 430,000 fingerlings of various sizes were implanted with coded wire tags and released in nursery habitats along the windward coast of Oahu between 1993 and 1998. Because few Pacific threadfin were present in creel surveys conducted between 1994 and 1998, Oahu fishermen were offered a $10 reward for each threadfin that was caught (for both hatchery-reared and wild fish). A total of 1882 Pacific threadfin were recovered from the reward program between March 1998 and May 1999, including 163 hatchery-reared fish, an overall contribution of 8.7% to the fishery. Hatchery-reared fish accounted for as high as 71% of returns in the release areas. Hatchery-reared fish were recovered on average 11.5 km (SD=9.8 km) from the release site, although some had moved as far away as 42 km. Average age for recovered hatchery-reared fish was 495 days; the oldest was 1021 days.

Cultured Pacific threadfin juveniles survived and recruited successfully to the recreational fishery, accounting for 10% of fishermen's catches on the windward side of Oahu. Recruitment to the fishery was highest for the 1997 release year; few juveniles from earlier releases were observed. Presence of a few large, fully developed females in the recreational fishery suggested that hatchery-reared fish can survive, grow, and reproductively contribute to the population. Implementation of an enhancement program that is focused on juveniles and perhaps large females, as part of an integrated fishery management strategy, could speed the recovery of this fish population.

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Declining marine fish stocks worldwide have led to an increased interest in marine fish stock enhancement (Blankenship and Leber, 1995; Schramm and Piper, 1995; Leber et al., 1996; Grimes, 1998; Howell et al., 1999). Stock enhancement of marine fishes has progressed since the late 1800s and several successful marine fish stock enhancement programs have been documented; however, nearly all have been directed toward temperate species such as chum salmon (Kaeriyama, 1996), Japanese flounder (Kitada et al., 1992), red sea bream (Imai et al., 1994; reviewed by Masuda and Tsukamoto, 1998), and red drum (McEachron and Daniels, 1995; McEachron et al., 1998). In one successful marine fish stock enhancement program in the tropics, hatchery-reared striped mullet (*Mugil cephalus*) successfully recruited to the fishery, accounting for 13% of the commercial mullet catch in Kaneohe Bay, Hawaii (Leber and Arce, 1996).

The Pacific threadfin (*Polydactylus sexfilis*), known locally as "moi," is the only representative of the threadfin family (Polynemidae) in Hawaii (Randall, 1996). The distribution of Pacific threadfin extends throughout the Indo-Pacific region from Madagascar (Bleeker, 1875) to the Ogasawara Islands of southern Japan, east to Hawaii and south to the Tuamotu Archipelago (Randall et al., 1990; Myers, 1991). In ancient Hawaiian culture, Pacific threadfin were reserved for the ruling chiefs and prohibited for consumption by commoners (Titcomb, 1972). Pacific threafin were formerly harvested commercially, but commercial catches have declined steadily since the 1950s and have essentially ceased since 1968 when the daily catch limit was restricted to 15 fish per person. This decline in abundance, particularly around the more populated areas of the state, is likely the cumulative result of years of chronic overfishing (Shomura[1]). Current regulations comprise the following: a catch limit of 15 fish per person per day; a minimum fish size of 7 inch. TL (ca. 14.5 cm FL) for caught fish; and a closed season from 1 June to 30 September.

Pacific threadfin are typically found over shallow sand flats, along high wave-energy rocky shorelines, and in sandy beach wash zone habitats (Hosaka, 1990; Leber et al., 1998). They can also be found in turbid water near stream mouths and brackish mangrove estuaries (Randall et al., 1990; Myers, 1991). Local fishermen call areas where adult Pacific threadfin congregate "moi holes" (Hosaka, 1990); these usually occur in shoreline caves or sandy depressions and sand channels in the surf zone among boulders or reef areas.

Pacific threadfin are protandric hermaphrodites, initially maturing as males after a year at about 20–25 cm; they then undergo a sex reversal, passing through a hermaphroditic stage and becoming functional females between 30 and 40 cm FL at about three years of age (Santerre and May, 1977; Santerre et al., 1979; Szyper et al., 1991). Spawning occurs inshore

[1] Shomura, R. 1987. Hawaii's marine fishery resources: yesterday (1900) and today (1986). Admin. Rep. H-87-21, 14 p. U.S. Dep. Commer., NOAA, NMFS, Southwest Fisheries Science Center, Honolulu, Hawaii 96822.

Table 1

Summary of Pacific threadfin (*Polydactylus sexfilis*) releases on the windward side of Oahu Island, 1993–97. Release size is fork length in mm.

Release year	Release sites	No. of fish released	Adjusted no. of fish released	% tag retention	Release size range (mm)
1993	Kahana	10,020	9939	99.2	70–150
	Laniloa	9990	9858	98.7	
1994	Kahana	40,530	37,888	93.5	48–130
	Malaekahana	40,695	37,561	92.3	
1996	Kahana	31,258	30,164	96.5	85–130
	Kailua	14,952	14,223	95.1	
1997	Kahana	99,020	96,019	97.0	70–130
	Kailua	97,569	94,349	96.7	
1998	Kahana	75,687	71,672	94.7	70–130
	Kailua	11,273	10,827	96.1	
Totals		430,994	412,500		

and eggs are dispersed and hatched offshore (Lowell, 1971). Larvae and juveniles are pelagic up to about 6 cm FL, at which size they enter inshore habitats including surf zones, reefs, and stream entrances (Santerre and May, 1977; Santerre et al., 1979). Newly settled young Pacific threadfin, locally called "moi-lii" (Lowell, 1971; Tinker, 1982), appear in shallow waters in summer and fall where they are the dominant member of the nearshore surf zone fish assemblage (Ziemann et al.[2]).

Pacific threadfin is a popular and much sought-after sport fish that also supports a small subsistence fishery in Hawaii (Santerre et al., 1979; Leber et al., 1998). It is presently an important species in the Hawaii recreational fishery because of its reputation as one of the best tasting fishes in Hawaii (Hosaka, 1990) and its high market value (wholesale market price over US$3.00 per kilogram). A species prioritization study conducted early in the stock enhancement research program in Hawaii identified Pacific threadfin as the top candidate for stock enhancement, based partly on the decline of its stocks, its high market value, and importance in the recreational fishery (Oceanic Institute[3]). As part of the Stock Enhancement of Marine Fish in the State of Hawaii (SEMFISH) program funded by the National Marine Fisheries Service, juvenile Pacific threadfin were released in nursery habitats along the windward coast of Oahu between 1993 and 1997 to evaluate the contribution of hatchery-reared fish to the local fishery. Leber et al. (1998) demonstrated site-specific potential success in stocking programs for juveniles in 1993–94. The purpose of this article is to provide long-term tracking of catches to determine the contribution of hatchery-produced fish versus wild stocks in the recreational fishery on the windward side of Oahu.

Methods

The culture of Pacific threadfin at the Oceanic Institute (OI) is described by Ostrowski et al. (1996). Most fish were released into coastal waters between day 60 for small juveniles (70–85 mm FL) and day 90 for larger juveniles (130–150 mm FL).

During each of five release years, 10,000 to 100,000 juveniles (per release site) were sorted by size and released in multiple lots over 3–5 months; the total number released per release site usually varied between years (Table 1, Fig. 1). Over the five release years, a total of 430,994 Pacific threadfin fingerlings were released. Before release, all fish received coded wire tags (Northwest Marine Technology, Inc., Shaw Island, WA: Jefferts et al., 1963) in the snout area to identify release lots by release size, date, and location. Approximately 5% of each release lot was retained in culture at OI to determine tag retention rates. Fish were examined monthly from 1 to 6 months until tag loss rates stabilized (i.e. when the number lost had not increased since the previous month). Tag retention rates varied from 93% to 99%. All calculations of tag recovery rates were based on coded–wire-tag data adjusted for tag retention rates.

We conducted a roving creel survey, encompassing all release areas, intermittently from 1994 to 1998 on the windward side of Oahu 1) to determine if released Pacific threadfin were surviving and being caught in the fishery, 2) to estimate Pacific threadfin CPUE in the recreational fishery, and 3) to inform fishermen about the Pacific threadfin

[2] Ziemann, D. A., A. M. Friedlander, and P. Craig. 1998. Enhancement of Pacific threadfin *Polydactylus sexfilis* in Hawaii. I. Release optimization. Stock Enhancement of Marine Fish in the State of Hawaii (SEMFISH), Phase IX, 152 p. Oceanic Institute, 41-202 Kalanianaole highway, Waimanalo, HI 96795.

[3] Oceanic Institute. 1989. Selection of marine finfish species for stock enhancement in Hawaiian waters, 78 p. The Oceanic Institute, Makapuu Point, 41-202 Kalanianaole Highway, Waimanalo, HI 96795.

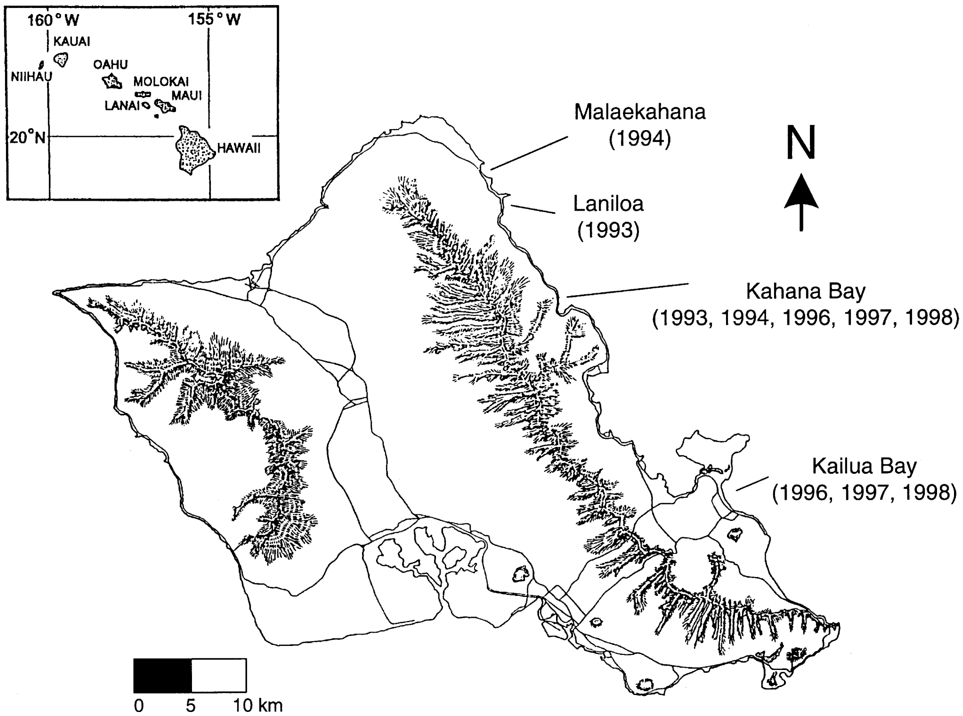

Figure 1

Island of Oahu, Hawaii showing locations for releases of hatchery-reared Pacific threadfin (*Polydactylus sexfilis*) from 1993 to 1998.

enhancement program. Fishermen were interviewed at boat docks and along the coastline to collect information about their catch and effort (species, lengths, number of hours fished per gear type). All Pacific threadfin in the catches were scanned for coded wire tags with a hand-held Northwest Marine Technologies cwt sensor ("wand").

Because Pacific threadfin were scarce in creel samples, we offered a $10 reward to Oahu fishermen for each Pacific threadfin (hatchery-reared and wild) caught in the open season between March 1998 and May 1999 (no retention is allowed from June to September). Posters, newspaper articles, and radio talk shows were used to publicize the reward program. We also informed participating fishermen that we were primarily interested in samples from the windward side of the island; thus, catches of Pacific threadfin from other parts of the island were underrepresented in our effort. To obtain the reward, fishermen provided date, location, gear used, fork length, and the head of each Pacific threadfin caught. Beginning in September 1998, fishermen had to return whole fish to obtain the $10 reward. This requirement allowed us to gather more accurate length information, as well as information on weight, sex, and gonadal condition. We obtained a relatively unbiased random sample from the fishery because fishermen were unable to determine visually whether a fish had a coded wire tag; this unbiased sample enabled us to calculate the contribution of hatchery-reared fish to the fishery.

A Mann-Whitney rank sum test (T-statistic) was used to compare distance traveled among sites and years for hatchery-reared fish. This test was also used to compare fork lengths of wild fish by sex between the 1999 and the 1962–68 sampling periods. We compared number of Pacific threadfin recovered in each size class in relation to the number of hatchery-reared fish released in that size class by using chi-square goodness of fit. Expected number of fish recaptured in each size class was calculated by taking the total number of recaptures for each year from each release site and multiplying it by the proportion of fish released in that size class at that site during that year.

A Kruskal-Wallis ANOVA on ranks with Dunn's multiple comparison procedure (Sokol and Rohlf, 1981) was used to identify pair-wise difference in CPUE among gear types; $\alpha = 0.05$. A two-way ANOVA (F) was conducted to compare fish length among gear types for wild and hatchery-reared Pacific threadfin during each reward year. Tukey multiple comparison procedures were conducted to determine pair-wise differences in fish length between gear types; $\alpha = 0.05$. Condition factor was calculated as

$$C = (W/L^3) \times 10{,}000,$$

where C = condition factor;
W = fish weight in grams; and
L = fork length in mm (Anderson and Neumann, 1996).

Table 2

Results of catch and effort from recreational creel surveys for Pacific threadfin conducted along the windward coast of Oahu between 1994 and 1998.

Gear type	Number of interviews	Total effort (h)	Number of threadfin	CPUE (number/h)	Number of hatchery-reared threadfin	Proportion hatchery-reared
Angling	464	3647	123	0.03	40	0.33
Gillnet	22	327	35	0.11	1	0.03
Throw net	42	93	3	0.03	0	0.00
Spear	23	81	0	0.00	0	0.00
Total	551	4148	161	0.04	41	0.25

Table 3

Summary of wild and tagged Pacific threadfin obtained from the recreational fishery from March 1998 to May 1999.

	1998				1999				Total			
Region	Hatchery-reared	Wild	Total	Proportion hatchery-reared	Hatchery-reared	Wild	Total	Proportion hatchery-reared	Hatchery-reared	Wild	Total	Proportion hatchery-reared
Ewa	0	18	18	0.00	0	0	0	0.00	0	18	18	0.00
Kahana	2	15	17	0.12	6	129	135	0.04	8	144	152	0.05
Kailua	35	14	49	0.71	4	6	10	0.40	39	20	59	0.66
Kaneohe	5	85	90	0.06	28	221	249	0.11	33	306	339	0.10
Laie	11	237	248	0.04	17	373	390	0.04	28	610	638	0.04
Mokapu	0	13	13	0.00	34	317	351	0.10	34	330	364	0.09
Mokuleia	0	8	8	0.00	0	0	0	0.00	0	8	8	0.00
North Shore	3	121	124	0.02	0	3	3	0.00	3	124	127	0.02
Sandy Beach	1	32	33	0.03	0	9	9	0.00	1	41	42	0.02
Waianae	0	18	18	0.00	0	0	0	0.00	0	18	18	0.00
Waimanalo	9	16	25	0.36	8	84	92	0.09	17	100	117	0.15
Total	66	577	643	0.10	97	1142	1239	0.08	163	1719	1882	0.09

Condition factors between sites and among release size classes were compared by using a two-way ANOVA (F); $\alpha = 0.05$. A Mann-Whitney rank sum test (T) was used to compare the gonadosomatic index (GSI=ovary weight/body weight×100) between hatchery-reared and wild Pacific threadfin recovered in the 1999 reward program.

Results

CPUE for Pacific threadfin from 551 creel survey interviews of recreational fishermen from 1994 to 1998 was very low (0.04 fish/h for all gear types combined) (Table 2): 1 per 33 hours by angling or 1 per 9 hours by gillnet. These values are probably low estimates because the creel survey was not directed at fishermen who targeted Pacific threadfin. Even though we saw a very small number of Pacific threadfin in the creel surveys, hatchery-reared fish made up 33% (40 of 123) of the angling catch and 25% (41 of 161) of the overall catch.

The voluntary reward program between March 1998 and May 1999 yielded 1882 Pacific threadfin (Table 3), of which 163 were hatchery-reared Pacific threadfin (8.7%). The period March–May 1998 provided 643 Pacific threadfin, compared to 1239 for the period September 1998–May 1999. Tag information was readable for 63 of 66 fish recovered in 1998 (3 damaged tags) and all 97 tags recovered in 1999. Of the total readable tags, fish released in 1997 made up 93.7% (n=59) of the 1998 reward fish and 95.9% (n=93) of the 1999 reward fish. Four fish from 1996 releases were recovered in each year. Although most fish recovered in the reward program were from the windward or eastern side of Oahu, 168 fish (26.1%), including 4 hatchery fish from the North Shore area, did come from other areas around the island in 1998 (Fig. 2). Three reward fish were returned from the North Shore in 1999. No hatchery-

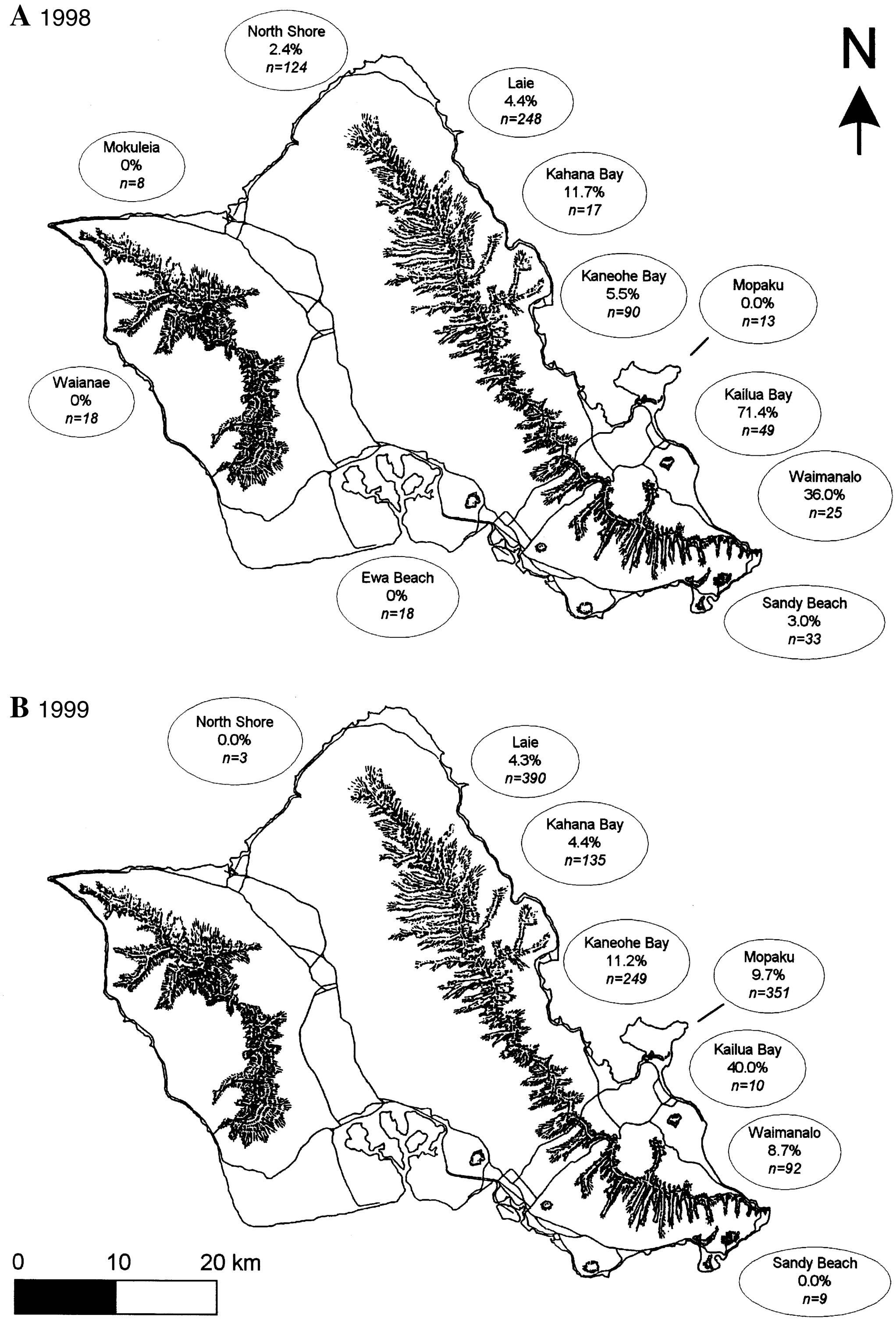

Figure 2

Percentage of hatchery-reared Pacific threadfin recovered from the recreational reward fishery program during the (**A**) 1998 and (**B**) 1999 fishing seasons. n = the total number of Pacific threadfin recovered at each site.

Table 4

Number of 1997 released fish obtained from the reward fishery for the years 1998 and 1999. Expected values were derived from the total number of hatchery-reared fish returned during each reward year from each release site, multiplied by the proportion of fish released in each size class. No χ^2 value was significant at $P < 0.05$.

Release size (mm)	Adjusted no. of fish released	1998		1999	
		Hatchery-reared	Expected	Hatchery-reared	Expected
Kahana					
70–85	14,152	5	2.51	8	5.45
85–100	34,618	5	6.14	16	13.37
100–115	41,069	6	7.27	11	15.83
115–130	6,102	1	1.08	2	2.35
Total	96,019	17	17.00	37	37.00
χ^2			2.91		3.24
Kailua					
70–85	15,415	9	6.86	14	9.15
85–100	35,090	19	13.62	17	20.83
100–115	37,819	14	16.84	25	22.45
115–130	6,022	0	2.68	0	3.57
Total	94,349	42	42.00	56	56.00
χ^2			4.56		7.14

reared fish were recovered from the leeward coast or south shore areas. Highest proportions of hatchery-to-wild fish were found in Kailua Bay (71%) and at Waimanalo Beach (36%) during the 1998 season. For the Kahana Bay site, around 12% of the Pacific threadfin recovered in the 1998 reward program were hatchery-reared. For the 1999 reward program, Kailua Bay continued to have the highest percentage of hatchery-reared Pacific threadfin, 40%. Hatchery-reared Pacific threadfin were also recovered at Waimanalo Beach (8.7%), Mokapu Peninsula (9.7%), and Kaneohe Bay (11.2%); the latter two sites are north of the Kailua Bay release site.

Hatchery-reared Pacific threadfin released in Kahana Bay were recovered as far north as Kawela Bay (25 km) and south to Waimanalo Beach (33 km) (Fig. 3). Fish released in Kailua Bay were recovered 19 km to the south at Sandy Beach and 42 km to the north at Kahuku (Fig. 4). Fish were captured at significantly greater distances from the release sites in 1999 ($\bar{x}$=15.2 km, SD=10.2) than in 1998 ($\bar{x}$=11.0 km, SD=6.8) (T=2044.0, P=0.025). Fish released in Kahana Bay were recaptured at significantly greater distances from the release site ($\bar{x}$=14.6 km, SD=11.0) compared to the Kailua Bay releases ($\bar{x}$=9.6 km, SD=6.3; T=6129.0, P<0.001).

The proportion of fish recaptured in the reward program for 1998 and 1999 was lowest in the largest release size class (115–130 mm) and greatest in the middle two release size classes (85–100; 100–115 mm). Because the number of fish released in each size class in 1997 was different, it was necessary to compare the number of fish recovered in each size class in relation to the number released in that size class. Eight fish recaptured from the 1996 release were not included in our analyses. For both years and both locations, the catch of hatchery-reared Pacific threadfin divided by the adjusted release number was greatest in the smallest size class (70–85 mm) (Table 4).

Expected number of fish recaptured in each size class was calculated by taking the total number of recaptured fish for each year from each release site and multiplying it by the proportion of fish released in that size class at that site during that year (Table 4). There were no significant differences in number of fish recaptured in each size class in relation to expected recapture numbers for both years at the Kahana Bay release site (1998: χ^2=2.91, df=3, P>0.05; 1999: χ^2=3.24, df=3, P>0.05) and for Kailua Bay (1998: χ^2=5.74, df=3, P>0.05; 1999: χ^2=7.14, df=3, P>0.05).

Angling (pole and line fishing) accounted for the greatest number of hatchery-reared and wild Pacific threadfin acquired in the reward program but had the lowest CPUE among gear types (Table 5). Over both survey years, for wild and hatchery-reared fish combined, angling accounted for 63.0% of the total Pacific threadfin catch, followed by gillnets (19.2%), thrownets (13.9%), and surround nets (3.9%).

Length of Pacific threadfin caught varied among gear types, between years, and between hatchery-reared and wild Pacific threadfin. For 1998, mean size of Pacific threadfin captured was significantly different among gear types (F=6.378, df=3, 632, P<0.001) and between hatchery-reared and wild fish (F=11.833, df=1, 632, P<0.001). Gillnets tended to catch larger fish, and surround nets captured the smallest fish (Tukey multiple comparison test results—gillnets: 255.5 mm ≥ angling: 235.1 mm ≥ thrownet: 214.0 mm > surround nets: 193.7 mm). Mean length for hatchery-reared Pacific threadfin pooled over all gear types was 207.0 mm (SD=28.6) and mean length for wild Pacific threadfin was 242.2 mm (SD=52.7).

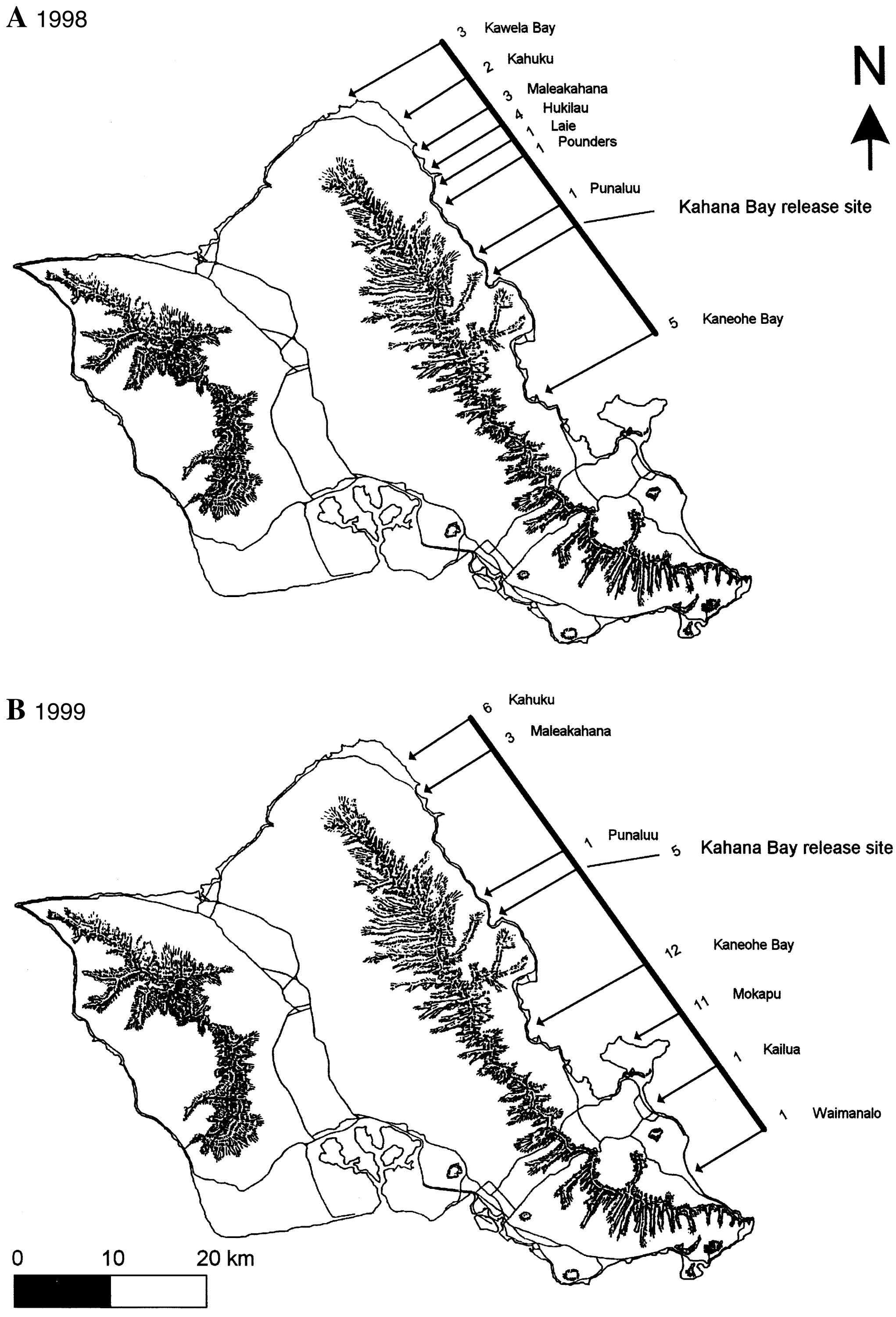

Figure 3

Movement patterns of hatchery-reared Pacific threadfin released in Kahana Bay from the reward fishery program during the (**A**) 1998, n = 20 and (**B**) 1999, n = 40 fishing seasons.

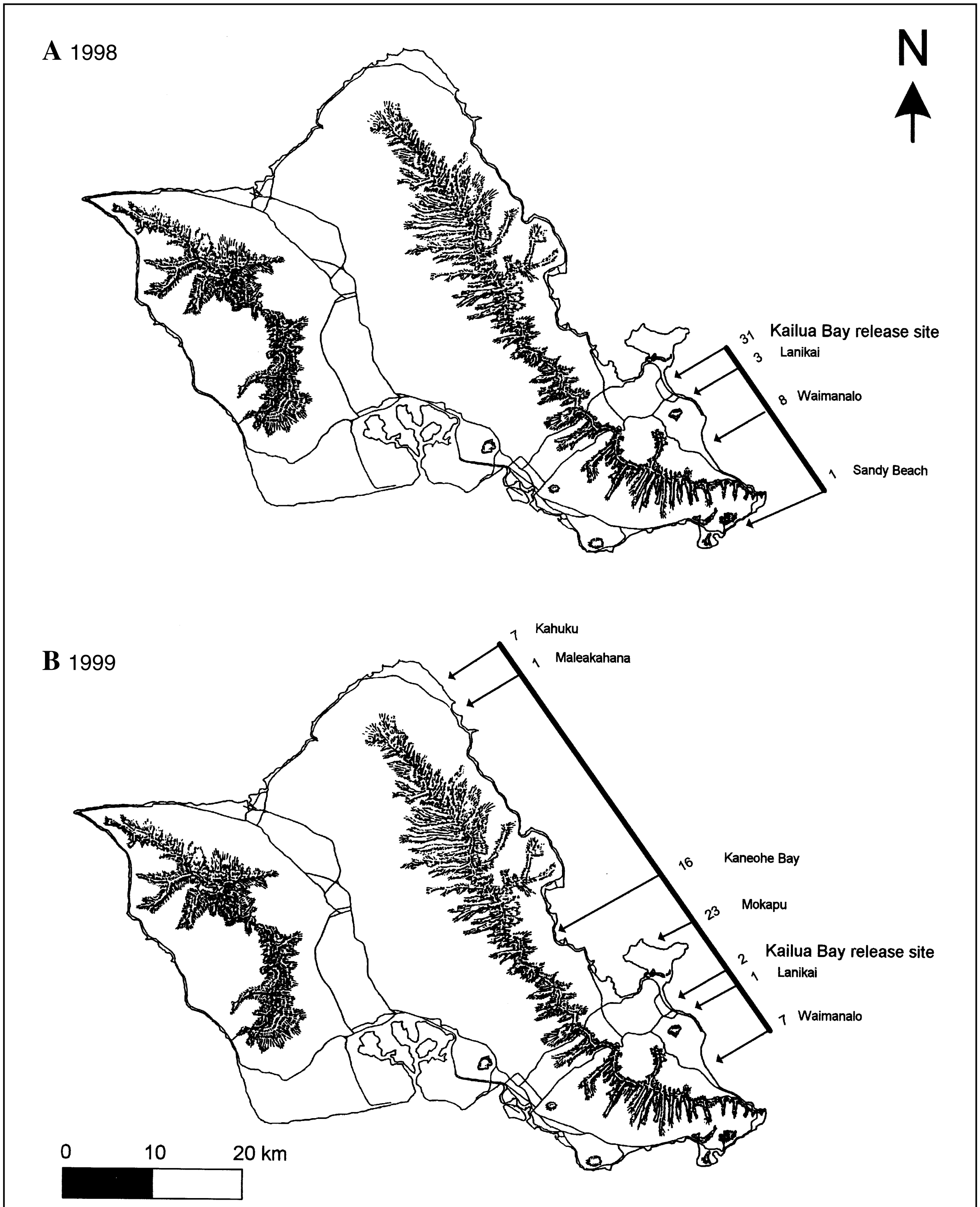

Figure 4

Movement patterns of hatchery-reared Pacific threadfin released in Kailua Bay from the reward fishery program during the (**A**) 1998, n = 43 and (**B**) 1999, n = 57 fishing seasons.

Information on sex of Pacific threadfin obtained in the reward program was available only during 1999 because whole fish were not acquired in 1998. The ratio of male to hermaphrodite to female was 56:17:27 for wild Pacific threadfin and 81:15:4 for hatchery-reared fish (Fig. 5). Three hatchery-reared fish that had changed from males

Table 5

Catch per unit of effort (CPUE) for Pacific threadfin caught by three different gear types used in the recreational-artisanal fishery. Mean rank computed for Kruskal-Wallis rank sum test (H=19.303, df=2, P<0.001). Results of Dunn's multiple comparison procedure. Gear types with the same letter (A, B) are not significantly different.

Gear type	*n*	Total hours	Total no. of threadfin	No hatchery-reared	Mean CPUE	SD CPUE	Dunn's multiple comparisons
Thrownet	16	55.0	166	7	5.49	9.34	A
Gillnet	31	83.5	221	20	3.52	4.89	A B
Angling	113	592.5	817	56	1.63	1.44	B
Grand total	160	731.0	1204	83	2.38	3.98	

Table 6

Comparison of size (mm FL) and sex for hatchery-reared and wild catch Pacific threadfin acquired from the reward fishery in 1999.

	Hatchery-reared				Wild			
Sex	Mean	Min.	Max.	*n*	Mean	Min.	Max.	*n*
Males	257.1	210	307	61	250.0	174	360	372
Hermaphrodites	267.2	220	323	11	275.0	200	380	112
Females	311.3	247	356	3	315.6	249	462	179

to females were recovered during 1999; one was released during summer 1996, the other two were released during summer 1997.

Mean size for males was 250.0 mm (SD=32.1) for wild fish and 257.1 mm (SD=24.8) for hatchery-reared fish; mean size for hermaphrodites was 275.0 mm (SD=27.5) for wild fish and 267.2 mm (SD=43.3) for hatchery-reared fish; mean size for females was 315.6 mm (SD=39.2) for wild Pacific threadfin and 311.3 mm (SD=57.1) for hatchery-reared threadfin (Table 6). The GSI for hatchery-reared males (x=0.629, SD=0.728) was not significantly different (T=6524, P=0.073) than the GSI for wild males (x=0.619, SD=0.842), likely because of the larger size of hatchery-reared males during 1999. Number of hatchery-reared females and hermaphrodites was too low for statistical comparisons.

Condition factor for hatchery-reared Pacific threadfin during 1999 was not significantly different between release sites (F=0.074, df=1, 79, P=0.786) or among release sizes (F=1.488, df=3, 79, P=0.224). Therefore, condition factors for all hatchery-reared fish were pooled and compared to condition factors for all wild fish recovered in 1999. No significant difference was found in condition factors between these two groups (T=47733.0, P=0.087).

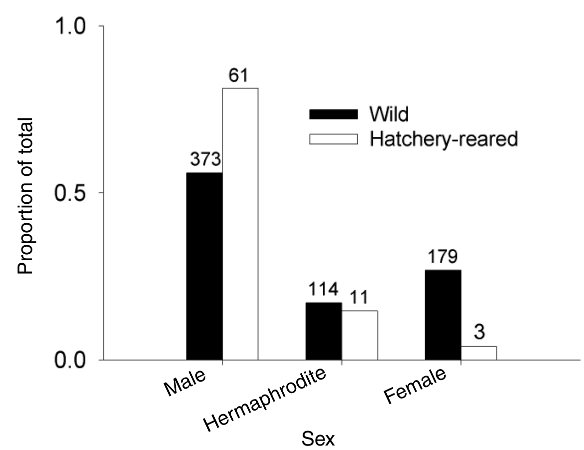

Figure 5

Sex ratio for wild and hatchery-reared Pacific threadfin returned for the 1999 reward fishing season. Values are total number of fish in each sex category.

Discussion

Cultured Pacific threadfin juveniles released into the ocean survived and recruited successfully into the recreational fishery, accounting for 10% and 8% of the catch on the windward side of the island of Oahu in two years (1998 and 1999, respectively). Hatchery fish from the 1997 release constituted the majority of the hatchery fish returns to the recreational fishery in 1998 (89.4%) and 1999 (95.9%). Few of the hatchery fish released in years prior to 1997 have been recovered from the recreational fishery. The large

Table 7

Comparisons of length of juveniles, males, hermaphrodites, and females for Pacific threadfin around Oahu from 1962 to 1968 and for wild fish from the 1999 reward fishery program. One standard deviation of mean fork length is shown in parentheses.

	1962–68, *n*=1651		1999 reward program, *n*=1105			
Sex	Fork length (mm)	Percentage of total	Fork length (mm)	Percentage of total	Mann Whitney *T*-value	*P*
Juveniles	227 (30)	6.4	191 (24)	39.7	44864	<0.001
Males	268 (29)	52.3	249 (35)	33.8	184831	<0.001
Hermaphrodites	317 (33)	17.8	275 (27)	10.3	11952	<0.001
Females	378 (45)	23.5	316 (39)	16.2	26200	<0.001

impact of a relatively small number of released fish on the recreational fishery shows that hatchery releases of limited numbers of fish have the potential to impact both the number of fish taken in the fishery and the rate at which the fishery can recover. The differences in contribution rates for different release years suggest that natural factors affecting the survival of juveniles, as well as early larval stages, vary between years.

Hatchery-reared and released fish collected in the recreational fishery showed growth rates, condition factors, and gonadosomal indices similar to those of wild fish, suggesting that hatchery-reared fish are able to adapt to the natural environment and integrate into the wild population. Our data (unpubl.) for wild and hatchery fish collected in nursery habitats showed no significant differences in growth rates. The mean size of hatchery-reared fish collected in 1998 was smaller than in 1999 (over 95% of the fish collected in 1998 and 1999 came from the same releases in 1997). Mean size for hatchery-reared fish in 1999 was not different from the mean size of wild fish for both years, which suggests that size of hatchery fish in 1999 represents the approximate size of 2–3 year-old threadfin and mean age of fish in the recreational fishery is also 2–3 years. The size-frequency distributions of hatchery and wild fish in 1998 and 1999 suggest that a significant portion of the wild fish in the fishery is younger than two years.

Small hatchery fish at release made a higher relative contribution to the recreational fishery than did the larger size group (but not significantly so, except for fish taken in Kailua Bay in 1999), and the nursery habitat sampling conducted after the 1997 releases showed the same (Leber et al., 1998; Ziemann et al.[2]). This pattern is in contrast to that observed for mullet in Hawaii (Leber, 1995) and Pacific threadfin for other years (Ziemann et al.[2])

Hatchery fish disperse slowly from the point of release along the windward coast of Oahu. In nursery habitats three months after release (Ziemann et al.[2]), hatchery fish represented in excess of 70% of the threadfin and they decreased within nine months to 10% or less. Some decrease is due to predation, but some is due to dispersal because in 1998, after 1 year at large, fish were caught in the recreational fishery a mean distance of 11.2 km from the release point, and after two years, mean distance had increased to 15.2 km. Dispersal from the two release sites differed: after one year mean distance for Kahana Bay releases was 14.6 km, whereas mean distance for fish releases in Kailua Bay was 9.6 km.

The 1999 reward sample contained 16% females, 44% males and hermaphrodites, and 40% immature fish. The life cycle of Pacific threadfin (protandric hermaphrodites) makes this skewed sex ratio even more problematic because individuals do not become functional females until about 30 cm FL and these larger fish are selectively removed from the population by fishing. For protogynous species, size-selective fishing mortality may result in differential loss of larger males (Sadovy, 1996; Beets and Friedlander, 1999). The percentage of juveniles in the catch was high. Mean size of Pacific threadfin in all sexual categories was significantly smaller than that reported by Kanayama[4] in 1962–68 (Table 7, Fig. 6); further, females constituted 23.5% of the catch in the 1960s, but only 16.2% of the catch in 1999. We demonstrated that cultured Pacific threadfin juveniles released in known nursery habitats survive and recruit successfully into the recreational fishery 1–2 years later. Our Pacific threadfin data indicate that recruitment of young fish to the population may be jeopardized because there are few mature females left in the population (recruitment overfishing), even with supplementation of hatchery-reared fish.

The underlying problem of the threadfin fishery on Oahu and the other Hawaiian Islands is primarily an intense local harvest by subsistence and recreational fishermen, as well as habitat loss from coastal and upland development. Current state regulations, as well as unregulated removal of larger individuals from the population, contribute to the male-biased sex ratios observed in our study. Stock recovery based on natural reproduction will be a long-term process. Implementation of an enhancement program for Pacific threadfin focused on juveniles and perhaps larger females could speed the rate of recovery of the local population.

[4] Kanayama, R. 1973. Life history aspects of the moi *Polydactylus sexfilis* in Hawaii, 50 p. State of Hawaii, Department of Lands and Natural Resources, Honolulu, Hawaii.

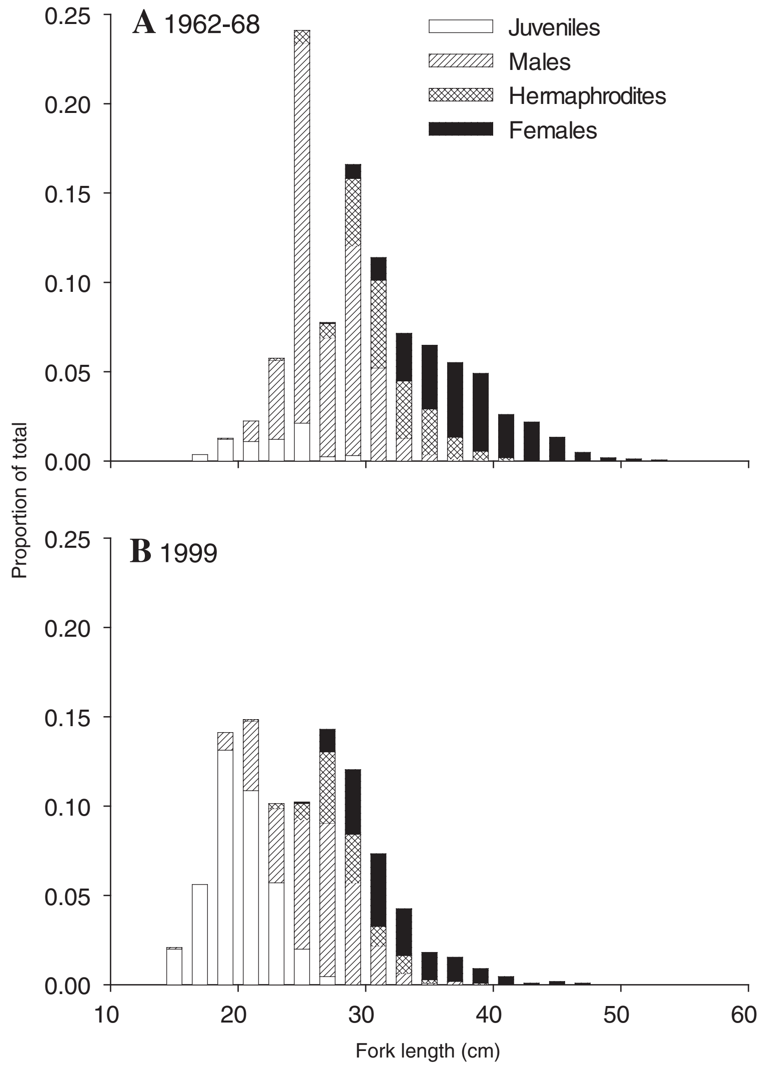

Figure 6

Proportion of juveniles, males, hermaphrodites, and females for Pacific threadfin from (**A**) 1962 to 1968 and (**B**) during the 1999 reward fishery program.

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