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Stock enhancement in a commercial mullet, *Mugil cephalus* L., fishery in Hawaii

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Abstract This study showed that cultured striped mullet, *Mugil cephalus* L., released as juveniles can make a significant contribution to landings in an island commercial fishery. Following pilot hatchery releases from 1990 to 1993, striped mullet fisheries in Kaneohe Bay, Hawaii, USA, were sampled to recover cultured fish from the bay-wide catch. Direct sampling of 181 fishing trips resulted in recovery of 211 cultured striped mullet. By autumn 1994, cultured fish comprised 13.0% (± 2.8%) of the commercial mullet catch in Kaneohe Bay, and the percentage was increasing logarithmically. This study corroborated predictions from previous studies of juveniles about effects of release strategies on survival of cultured mullet. Following summer releases, recapture rates were strongly affected by fish size-at-release, with a critical release size of 60 mm total length (the smallest size released that was subsequently detected in the fishery). Over 30 000 juveniles stocked in 1990 (but not in a nursery habitat preferred by striped mullet) apparently suffered complete mortality.

KEYWORDS: hatchery releases, recapture rate, sea ranching, survival.

Introduction

Decades after initial efforts failed to show any effects (Richards & Edwards 1986), attention is being refocused on the concept of releasing cultured organisms to supplement and restore declining coastal fisheries (marine stock enhancement). Fishery biologists now have access to the technology needed to evaluate stock enhancement potential. As coastal fisheries face severe over-exploitation and depletion worldwide (FAO 1992, 1994), it is time to resolve lingering questions about whether marine stock enhancement can help recover lost recruitment potential and supplement the abundance of wild stocks.

There is little published quantitative evidence that stocking cultured marine organisms (that spawn in seawater) into coastal areas results in recruitment of released individuals to fisheries. Notable exceptions include ongoing work in Norway and Denmark with cod, *Gadus morhua* L., (Svåsand, Jørstad & Kristiansen 1990; Danielssen & Gjøsæter 1994; Nordeide, Fosså, Salvanes & Smedstad 1994; Støttrup, Nielsen, Krog & Rasmussen 1994), in Japan with the flounder 'hirame' – *Paralichthys olivaceus* (Kitada, Taga & Kishino 1992) and the scallop *Patinopecten yessoensis* (Honma 1993), in the U.K. and France with lobster, *Homarus gammarus* L (Bannister & Howard 1991; Latrouite & Lorec 1991), and in Spain with turbot, *Scophthalmus maximus* (L.) (Iglesias & Rodríguez-Ojea 1994). Very few studies have quantified the percentage contribution of cultured marine finfish to commercial fishery landings (but see

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Svåsand *et al.* 1990; Kitada *et al.* 1992). Although published accounts of the effects of marine hatchery-releases on fishery landings are uncommon, considerable work to quantify marine, stock-enhancement recruitment dynamics has begun within the past decade (Tsukamoto, Kuwada, Hirokawa, Oya, Sekiya, Fujimoto & Imaizumi 1989; Svåsand & Kristiansen 1990; Barlow & Gregg 1991; Jørstad, Paulsen, Nævdal & Thorkildsen 1994; Stoner 1994; and other studies in symposia proceedings edited by Lockwood 1991, Danielssen, Howell & Moksness 1994, and Schramm & Piper 1995).

The marine stock enhancement concept is being evaluated in coastal waters in Hawaii, USA. Since 1989, a research programme, titled 'Stock Enhancement of Marine Fish in the State of Hawaii (SEMFISH),' has been conducting test releases in Hawaiian estuaries and shoreline marine habitats (Leber 1995; Leber, Brennan & Arce 1995; Leber, Arce, Blankenship & Brennan 1996a; Leber, Arce, Sterritt & Brennan 1996b).

In 1988, a semi-quantitative, species-selection process was used to identify marine finfish for stock enhancement research in Hawaii. The selection process involved federal, state and nonprofit-making organization and local representatives of the Hawaiian fisheries community. The marine fishes, Pacific threadfin, *Polydactylus sexfilis* Cuv. & Val., and striped mullet *Mugil cephalus* L. were the two highest ranked species (Leber 1994). After species were prioritized, and mass-culture techniques became available for striped mullet (Eda, Murashige, Oozeki, Hagiwara, Eastham, Bass, Tamaru & Lee 1991), pilot release-recapture experiments began, using striped mullet as the initial test species for SEMFISH research. In 1993, following development of production techniques for Pacific threadfin (Kelley, Bass & Leber 1995; Ostrowski, Iwai, Monahan, Unger, Dagdagan, Murawaka, Schivell & Pigao 1996), the first test releases began with that species (Leber unpublished data). The current paper reports on recruitment of cultured striped mullet, released in pilot studies from 1990 to 1993, to a commercial striped mullet fishery during 1993 and 1994.

In 1990 and 1991, release-recapture experiments were conducted to develop release protocols for testing the marine stock-enhancement concept with striped mullet in Kaneohe Bay, Hawaii (Leber 1995; Leber *et al.* 1996a). This site is the largest estuary in Hawaii, and extends 14 km along the island of Oahu's windward (east) coast. The resulting data on fish size-at-release, release habitat, and release-season effects on survival were used to redesign release strategies. Test releases were then conducted in 1992 and 1993 to evaluate key assumptions about the impact of hatchery releases on juvenile recruitment in a Hawaiian coastal environment (Leber *et al.* 1995; Leber *et al.* 1996b).

To evaluate the full potential of marine stock enhancement, results of pilot releases need to be quantified at various stages of the life cycle. Recruitment success and survival patterns during the juvenile stage are considered in the last four publications cited above. In this study, creel surveys were initiated in mid 1992 to examine growth and survival after cultured fish dispersed from their nursery habitats into habitats occupied by adults. The primary objectives were: (1) to determine if cultured striped mullet released as juveniles could survive and grow to mature adults and recruit to the local spawning stock; (2) to identify the percentage contribution of cultured fish in the local fishery; and (3) to determine if survival patterns of released fish changed after the juvenile stage, by comparing survival patterns of adult cultured fish captured in the bay-wide fishery to results from previous studies of juveniles in Kaneohe Bay nursery habitats.

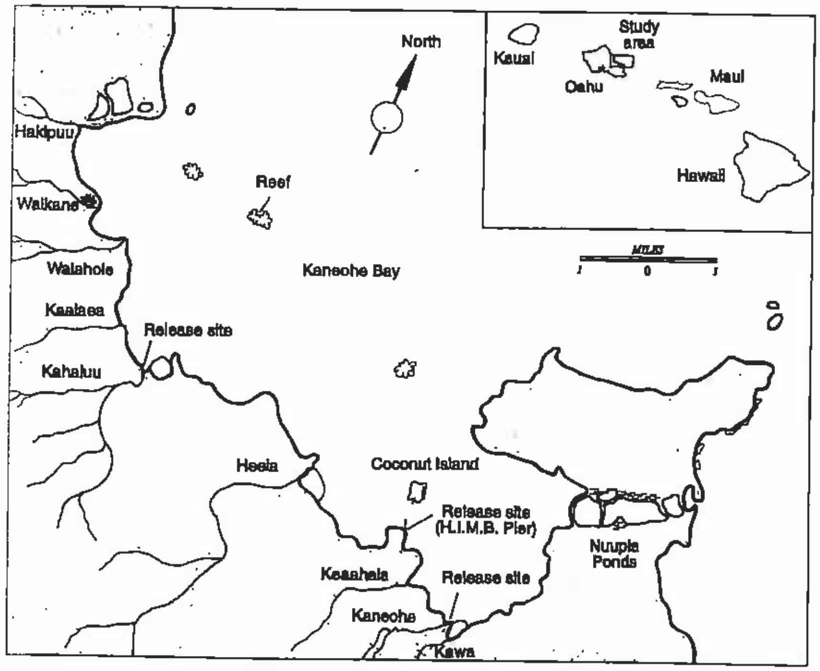

Figure 1. Map of Kaneohe Bay showing location of release sites.

In Hawaii, striped mullet are fished by commercial and subsistence net fishermen as well as by recreational pole-and-line fishing. However, recreational fishing for this species has long been on the decline throughout the islands. Historically, creel surveys in Hawaii began as a compilation of creel data collected *ad hoc* from coastal areas, and were often conducted without stratified statistical consideration and only for brief time periods. The need to develop a more quantitative inshore creel survey was identified as a priority by the Hawaii state Division of Aquatic Resources (HDAR) in 1990 (Kahiapo & Smith 1994). For a 28-month period (from March 1991 until June 1993), a survey of recreational and commercial fisheries was conducted by HDAR in Kaneohe Bay (Everson unpublished data). Because of the irregular fishing pattern of commercial fishermen who fish striped mullet in Kaneohe Bay, the commercial mullet catch was not a principal target of the HDAR survey.

This paper describes results from a separate creel survey designed to recover catch and hatchery contribution data from the Kaneohe Bay striped mullet fishery. This study revealed that pilot-scale hatchery releases conducted from 1990 to 1993 contributed to yields in that fishery.

Materials and methods

Between June 1990 and August 1993, ≈243 500 cultured striped mullet were tagged with binary-coded wire (Jefferts, Bergman & Fiscus 1963; Buckley & Blankenship 1990), and released into Kaneohe Bay (Figure 1; see Leber 1995; Leber *et al.* 1995 and Leber *et al.* 1996 in press, 1996b for details). The cultured fish were produced from wild parental stock at The

Oceanic Institute in Waimanalo, Hawaii, and reared to 45–130 mm long fingerlings, which were graded into five size groups prior to release. The coded-wire tags (CWT) identified fish size-at-release, release site, release magnitude, and release lot (date). A sampling programme was designed to recover cultured striped mullet from the fishery in Kaneohe Bay and document the hatchery contribution to catch-per-unit-effort (CPUE) in the fishery during 1992, 1993 and 1994. Sampling initially targeted the recreational and subsistence fisheries, but was redesigned in 1993 to target greater catches in the commercial fishery.

Initial approach to sampling mullet fisheries in Kaneohe Bay

In 1992, potential recreational and subsistence fishing areas were identified. Sites popular with these fishermen in Kaneohe Bay were systematically sampled with a roving creel survey. Initial contact interviews focused on determining the most frequently fished areas and encouraging cooperation with efforts to retrieve tagged, adult striped mullet. Roadside areas and boat ramps in Kaneohe Bay were surveyed to collect creel data. A roving creel survey was also initiated in Maunalua Bay, on Oahu's south shore, to examine recreational fishing effort. Cultured striped mullet were released in Maunalua Bay in 1989 and 1990 (Leber 1995).

Creel survey activities followed a structured sampling schedule to obtain basic catch information. Initial surveys were stratified around area, time, and gear to provide catch and effort data. The sampling design also evaluated participation levels (total effort by location and time of day). Data collectors obtained fishing trip information, catch data, and tagged mullet from both complete and incomplete fishing trips. Striped mullet catches were sampled for tagged fish using a tag detector. Estimates of CPUE were obtained by dividing measured harvest by measured effort.

A public awareness programme was initiated to highlight programme objectives and to elicit support from the fishing community. Fishermen were contacted and informed of stock enhancement activities. Additional insight was sought from fishermen regarding current and historical fishing trends within Kaneohe Bay. A list of potentially cooperative individuals was identified and compiled, and they were contacted to enlist their assistance in obtaining additional catch and fishing effort data.

Modified creel sampling approach targeting the most successful fishermen

After creel census activities in summer and autumn 1992 resulted in catch data totalling only four striped mullet, the approach was modified to include sampling of the commercial fisheries. The survey was confined to Kaneohe Bay. Project biologists contacted local fish wholesalers and retailers at the Honolulu fish auction at the beginning of the fishing season in March 1993. Through informal interviews conducted at the auction, better insight was gained about the structure of the fishery. Most striped mullet fishing on Oahu was commercial, and many 'subsistence' fishermen held commercial licences to sell their catch.

A new approach was developed, aiming to identify those principally fishing commercially for striped mullet in Kaneohe Bay, and to obtain the largest sample possible from that fishery. Effort was refocused in two directions: (1) sampling the Kaneohe Bay striped mullet catch sold in local fish markets and (2) direct sampling of the commercial catch in Kaneohe Bay.

Discussions with local fish-market owners were expanded to gain their cooperation and sample catches of local striped mullet brought to their markets. Fish-market owners were contacted weekly to sample mullet catches. Maintaining regular contact with fish-market owners also expanded the list of identified commercial striped mullet fishermen in the bay, as a trusting relationship was developed with the owners.

Next, direct contacts were made with commercial fishermen in Kaneohe Bay to inform them of SEMFISH activities and to elicit their cooperation in retrieving tagged adult striped mullet. After developing contacts in the field, a SEMFISH researcher either participated as crew in fishing excursions and sampled the mullet catch *in situ*, or waited at the dock and sampled the catch. This generated data on gear type, time spent fishing (effort), total catch per trip, and proportions of cultured and wild fish caught. These data provided reliable estimates of CPUE (where SEMFISH biologists participated as crew members) and provided data on percentage contribution of cultured fish in the catch.

The modified creel surveys were run concurrently during the open fishing season for striped mullet, from March through November, in 1993 and in 1994. Cultured fish were detected in catch samples from surround nets, gill nets and cast nets using field sampling detectors (Northwest Marine Technology Inc., Shaw Island, WA, USA) to detect coded-wire tags. All tagged fish were supplied without cost when project staff worked as crew on board vessels; otherwise, the wholesale price was paid for tagged fish.

Some individuals were unwilling to cooperate directly, but their catches were often sampled indirectly at the fish-markets they supplied. Information was often provided by cooperative persons when a commercial catch by an uncooperative individual was taken to market. On many such occasions, it was possible to track these catches to the receiving fish-market and sample them there.

To increase project awareness, project biologists conducted informal meetings with the Kaneohe Bay fishing community, and provided an informative pamphlet soliciting help from fishermen in retrieving tagged adult fish. Pamphlets were also widely distributed to local fishing-tackle shops.

Tag-data retrieval

All tagged fish were placed on ice and returned to the laboratory where the tags were recovered and each fish was weighed and measured. Tags were located and extracted from the snout using a field sampling detector and a binary search pattern. Tags were decoded using a binocular microscope (×40). To verify tag codes, each tag was read twice (by separate technicians). Data were analysed using SYSTAT (Wilkinson 1990). Systat Basic was used to write tag decoding algorithms. For each recaptured fish, the algorithms identified release date; batch size; release lot; release site; size-at-release and release season, based on the tag codes. Average growth rate was computed for each individual recaptured by dividing change in length (the difference between length at capture and the median length within SAR group) by weeks at sea. Proportions were arcsine transformed prior to statistical analysis. Variance estimates are expressed throughout as standard errors.

Results

Initial survey of recreational fishing in 1992

A total of 130 survey trips were made at roadside and boat-ramp sites around Kaneohe Bay and Maunalua Bay between 15 August and 30 November 1992. Only six recreational mullet fishermen were located and sampled, all on separate occasions. One possessed two striped mullet taken with pole-and-line gear, and two had one striped mullet each, which were captured with a gill net and a cast net. All four fish were wild, and all were captured at Wailupe Beach Park in Maunalua Bay.

The 1992 results indicated that Kaneohe Bay and Maunalua Bay had little pole-and-line recreational fishing. Because of the small sample size, an accurate CPUE estimate for wild striped mullet could not be obtained.

During the 1992 mullet fishing season the focus was on recreational fishing; however, results of contact interviews indicated that most fishing effort in Kaneohe Bay was commercial. An increase in commercial fishing effort was noted as the season came to a close on 1 December 1992.

Modified survey targeting commercial fishing in 1993 and 1994

Principal gear types. Field contact with expert fishermen and with biologists working on the state creel survey identified the two most successful methods of mullet fishing in Kaneohe Bay as surround netting (with a seine) and gill netting. The work to contact and inform commercial fishermen of project objectives helped secure direct access to catch and effort information for both types of fishing gears. Dimensions of the surround nets used were 762 m long, 18.3 m deep, 6.99 cm stretched mesh. The surround net was set by boat around schools of mullet; then a winch was used to harvest the catch. Surround net fishing excursions lasted ≈4 h and were manned by a crew of five, which included a SEMFISH project biologist on the majority of trips sampled.

The average size of gill net used was 190.5 m long, 2.13 m deep, 7.62 cm stretched mesh. Typically, five sections of gill net (38.1 m length) were set for each effort in a specific configuration and area. Gill nets were set and harvested by a one or two-person crew, either by small boat or manually, depending on the area and habitat, and were set for ≈4 h. The fishermen surveyed in this study targeted striped mullet and were considered experts in fishing skill and experience.

Survey participation. The creel survey in 1993–1994 comprised of seven individuals whose catches were sampled either directly by SEMFISH researchers or indirectly through the fish markets they supplied. Over the 2-year study period 181 fishing trips were sampled, including 107 surround net catches, and 74 gill net catches. Catch and effort data obtained directly from the field from surround nets and gill nets comprised 84.1% and 78.1%, respectively, of the total data collected for these fishing gears. The remainder was obtained indirectly through fish markets.

Catch per unit effort (CPUE). Quarterly catch statistics, including total effort, total catch and CPUE are presented by gear type in Table 1. To estimate CPUE (expressed as number of fish per hour of effort) within gear types, the 'total ratio estimator' was used (sum of measured catch over all sampling days divided by the sum of measured effort over all sampling days). This ratio is self-weighting, i.e. it is influenced by differences in daily fishing effort and is representative of fishing success for the population as a whole (Malvestuto 1983). Individual statistics are not presented in Table 1 for cast-net gear because of a paucity of samples (only a single interview).

Of the two basic gear types encountered, surround nets afforded the greater total catch and CPUE throughout the study, except in summer 1994 (Table 1). Within gear types, mean CPUE was similar in 1993 and 1994 for data combined over the three quarters (spring, summer and autumn) of the open fishing season.

Contribution of cultured fish to the catch. During the 2 years that the modified creel survey was conducted, a total of 4119 striped mullet were sampled from the Kaneohe Bay fishery. Of these, 211 were tagged, cultured fish released in pilot studies from 1990 to 1993. In 1994, surround-net fishing yielded a mean of 7.22% (± 4.32%) cultured fish per catch event, nearly double that during the same period in 1993 (Table 1). Cultured fish comprised 5.88% (± 3.85%) of the mullet caught in gill nets in 1994, compared to 0.71% (± 0.37%) of the catch in 1993 (Table 1).

Pooling data from the two gears revealed a steady and significant increase in the percentage contribution of cultured fish to the commercial striped mullet fishery during 1993–1994 (Figure 2; ANOVA, $P < 0.001$, $F = 9.07$, d.f. = 103). Contributions of cultured fish in 1994 were significantly greater than those in 1993 (separate-variances t-Test, $P < 0.001$, $t = 4.1$, d.f. = 49.9, Wilkinson 1990). By autumn 1994, cultured fish comprised 13.01% (± 2.79%) of the commercial striped mullet catch in Kaneohe Bay, and this figure was increasing logarithmically.

Cultured striped mullet recovered from the fishery ranged in size from 270 mm total length (TL) (191 g) to 467 mm (906 g). Cultured fish entered the fishery as early as 59 weeks after release (270-mm individual, released in summer 1992). The next earliest entries were six cultured fish released in the summer of 1993, which averaged 340 mm in length (360 g) after 66–67 weeks in the wild, and which were all recovered in autumn 1994. The three oldest fish recovered were released in 1990, recaptured after 229 weeks, and averaged 377 mm TL (570 g). For samples of 20 or more fish, average growth ranged from 1.9–2.5 mm per week (Table 2). Growth rate decreased with age (Figure 3, $r^2 = 0.67$, $P < 0.001$). There was considerable size variation among Size-at-release (SAR) groups, and length was weakly correlated with weeks after release (Figure 4, $r^2 = 0.29$, $P < 0.001$).

An additional 39 cultured striped mullet were recovered from the commercial fishery in Kaneohe Bay during the first 14 days in March 1995. The cultured fish averaged 14.4% (± 3.5% std. error, $n = 9$ fishing trips sampled) of the commercial catch.

Release history and relative survival

Release year. Tag codes revealed that the majority (56.4%) of the 211 cultured striped mullet retrieved from the commercial fishery in Kaneohe Bay were released into the bay in 1992 at

Table 1. Catch and effort data from creel samples of selected commercial striped mullet fishermen in Kaneohe Bay during 1993–1994. Unit effort is fishing hours. Catch-per-unit-effort (CPUE) is for the combined catch of wild and cultured striped mullet. Mean contribution rate (Mean C.R.) is the average proportion of cultured fish in the catch. Standard errors (SE) are based on a sample size of three seasons per year.

Gear type	Spring 1993	Summer 1993	Autumn 1993	1993 total	SE	Spring 1994	Summer 1994	Autumn 1994	1994 total	SE	1993–1994 total	SE
Total catch	184	317	1209	1710		1379	36	994	2409		4119	
Cultured	9	2	28	39		51	2	119	172		211	
Surround net												
Total catch	102	261	1061	1424		1257	0	792	2049		3473	
Total effort	12	36	116	164		84	28	104	216		380	
CPUE	8.50	7.25	9.15	8.30	0.56	14.96	0	7.62	7.53	4.32	7.91	1.96
Mean C.R.	3.66	0.62	2.77	2.35	0.90	4.16	–	10.27	7.22	4.32	4.30	3.60
Gill net												
Total catch	82	56	127	275		122	36	202	360		635	
Total effort	60	44	84	188		52	56	72	180		368	
CPUE	1.36	1.27	1.63	1.42	0.11	2.35	0.64	2.81	1.93	0.66	1.68	0.32
Mean C.R.	0	0.89	1.23	0.71	0.37	0	4.5	13.13	5.88	3.85	3.29	2.08

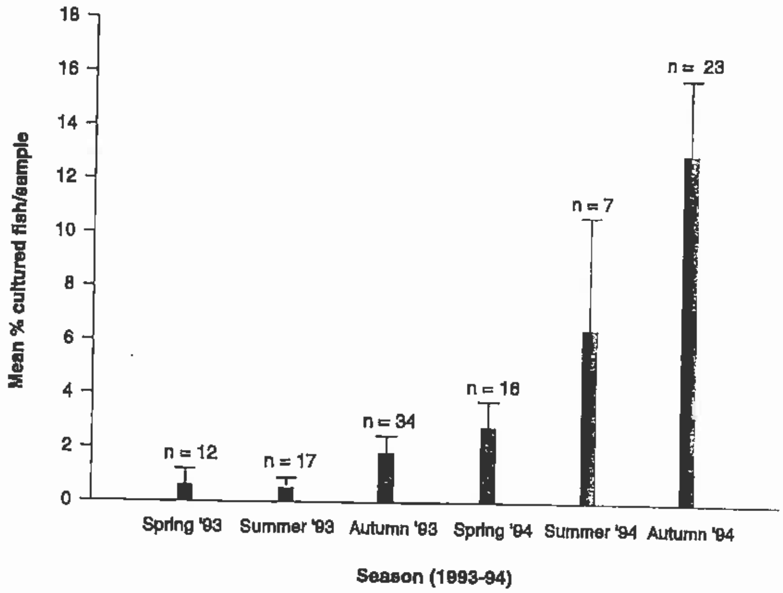

Figure 2. Mean percentage contribution of cultured striped mullet in samples taken from the commercial mullet fishery in Kaneohe Bay. Sample size (n) = number of catches sampled in which striped mullet were landed. Fishing trips sampled where no mullet were landed are excluded.

Table 2. Release study and release site of 210 cultured fish retrieved from the commercial fishery in Kaneohe Bay. Abundance data are total number recovered and mean recovery rate (number caught/number released) per release lot for fish collected during creel interviews in 1993 and 1994. Numbers released and numbers of experimental replicates (Lots) per release site varied among years.

Release Year	Release location	Number recovered	Total released	Lots	Mean recovery rate	SE	Mean length (mm TL)	SE	Growth (mm × Wk^{-1})	SE
1990	Kahaluu Inlet	20	11 676	2	0.18%	0.05	410	17.73	1.90	0.20
1990	HIMB Pier	0	31 146	3	0.00%	–	–	–	–	–
1991	Kahaluu Inlet	55	45 362	6	0.12%	0.02	369	3.91	2.04	0.02
1991	Kaneohe Inlet	10	45 455	6	0.02%	0.01	399	6.47	1.88	0.09
1992	Kahaluu Inlet	68	40 223	6	0.17%	0.02	357	5.17	2.47	0.03
1992	Kahaluu Lagoon	51	40 284	6	0.13%	0.03	364	3.23	2.31	0.05
1993	Kahaluu Lagoon	6	29 354	3	0.02%	0.01	337	5.21	3.26	0.06

Kahaluu Stream (Table 2). Release history of one tagged fish could not be identified, because the tag was lost during extraction.

Recovery rates (number released/number recaptured) were significantly greater for fish released in 1992 than for those released in 1991 (ANOVA, $P < 0.005$, $n = 12$ separate releases

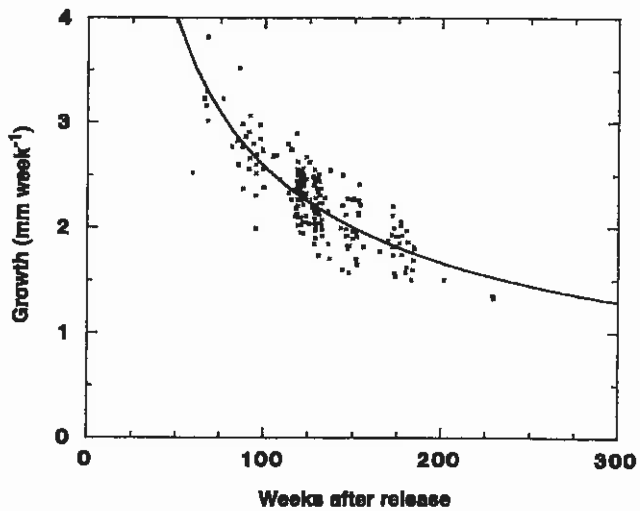

Figure 3. Decline in growth rate (mm total length per week) with age of cultured striped mullet recovered from the commercial fishery in 1993 and 1994.

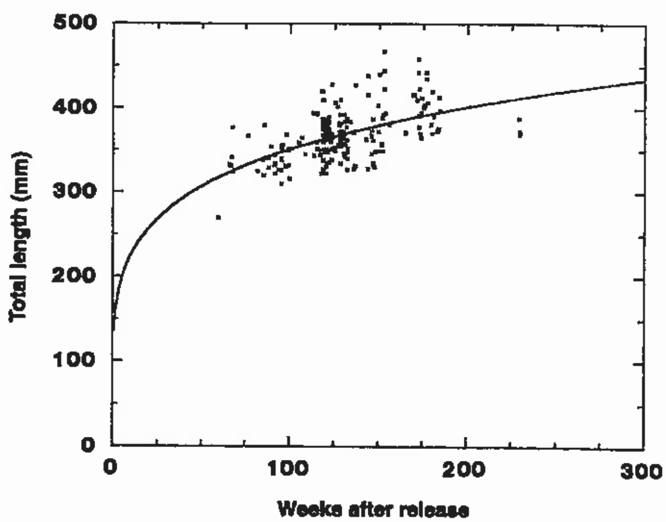

Figure 4. Total length (mm) of cultured striped mullet recovered from the commercial fishery.

each year). As expected, because of the short time period after release, recovery of fish released in 1993 was low relative to recovery of fish released during 1990–1992.

Release habitat. Recovery rates were significantly greater for fish released at Kahaluu Stream in 1990 than along the shoreline at the Hawaii Institute of Marine Biology (HIMB) access pier (ANOVA, $P < 0.02$, $n = 2$ release lots at Kahaluu and 3 lots at HIMB); the 31 146 fish released near HIMB pier apparently suffered complete mortality. There was also greater recovery from releases made in 1991 at Kahaluu Stream than from Kaneohe Stream ($P < 0.001$,

Table 3. Numbers of recaptured cultured striped mullet organized by time in the wild and size groups released. Time is given in quarter years. Recovery rate is number recaptured divided by number released, ×100 percent. Cultured fish from each size interval were released annually from 1990 through 1992. At the time of release, fish ranged in age from three months old (45 mm) to eight months old (130 mm). Only individuals greater than 70 mm TL were released in 1993.

		Size at release (mm TL)				
Quarter years at sea	Number recovered	45–60	60–70	70–85	85–110	110–130
5	1	–	–	–	–	1
6	6	–	–	–	–	6
7	5	–	–	1	3	1
8	21	2	1	8	7	3
9	4	–	–	4	–	–
10	67	–	3	32	32	–
11	42	6	13	8	9	6
12	16	2	3	6	5	–
13	17	2	4	3	8	–
14	2	–	–	1	1	–
15	22	1	3	13	5	–
16	3	–	2	1	–	–
17	1	–	–	–	1	–
18	3	–	2	1	–	–
Total	210	13	31	78	71	17
Number released:	243 498	46 774	53 478	86 334	44 451	12 461
Recovery rate:	0.086%	0.028%	0.058%	0.090%	0.160%	0.136%

$n = 6$ lots). Release habitat had no significant effect on recovery rates of fish released in 1992 at two locations within Kahaluu Stream (upstream lagoon vs. stream mouth; $P > 0.28$, $n = 6$ lots).

Size-at-release and release season. Recovery rates were directly related to fish SAR, with disproportionately low survival of fish that were smaller that 70 mm TL when released (Table 3). Recovery rates of fish larger than 85 mm when released were ≈5 times greater than those for fish that were smaller than 60 mm when released.

SAR effect was strongly significant ($P = 0.003$, $n = 14$ replicate release lots) when data were pooled across years (including fish from releases in 1990, 1991 and 1992; but excluding fish from 1993 releases, as the largest fish released in 1993, 110–130 mm, were just beginning to enter the fishery at the end of the study period).

Cultured fish were released during different times of the year (release seasons) to evaluate the effect on survival of the timing of releases (spring and summer) relative to natural juvenile recruitment pulses (spring). The direct effect of SAR on recovery rate was strongest after summer releases (Figure 5, ANOVA, $P = 0.011$, $n = 8$ lots). Although not statistically significant ($P = 0.20$, $n = 6$ lots), there was a strong trend in the pooled data towards size-at-release dependent survival following spring releases (Figure 6). Compared to results from

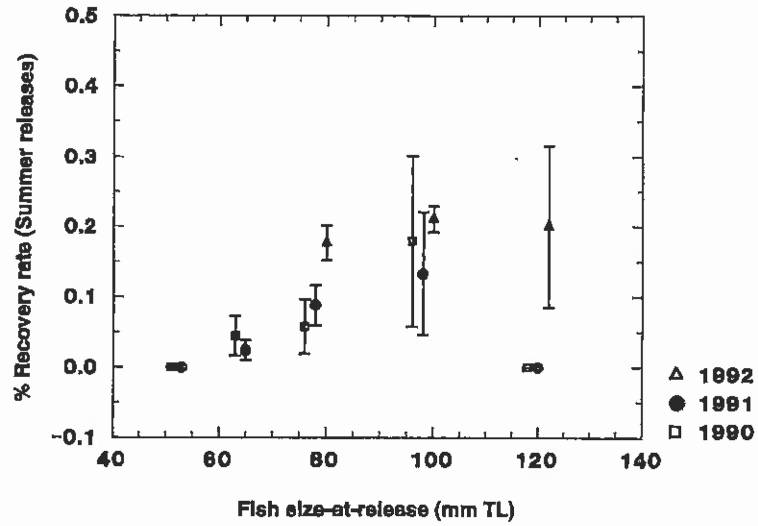

Figure 5. Mean percentage recovery rate ([number recaptured/number released] × 100%; ± SE, n = number of replicate release lots) of cultured fish in the commercial mullet fishery following summer releases into Kaneohe Bay. Data within release years are plotted against medians of the five size-at-release (SAR) intervals and offset around each SAR median on the x-axis for clarity. SAR intervals were 45–60 mm, 60–70 mm, 70–85 mm, 85–110 mm, and 110–130 mm total length.

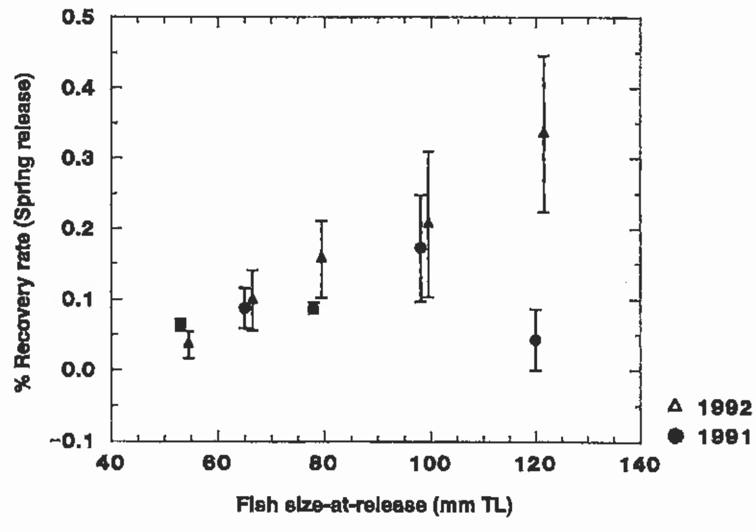

Figure 6. Mean percentage recovery rate in the commercial mullet fishery following spring releases of five size intervals of cultured striped mullet into Kaneohe Bay. See Figure 5 legend for details.

summer releases, there was better survival of fish below 70 mm when released in the spring. No fish were recovered from the smallest SAR group (45–60 mm) when releases were made in the summer (Figure 5). In comparison, 13 of the smallest fish released in spring (45–60 mm) were recovered in the fishery from the studies that included spring releases (1991 and 1992;

Figure 6). Only one individual from the largest SAR group (110–130 mm) was recovered from 1990 and 1991 releases. By contrast, 10 individuals from the 110–130 mm group were recovered from 1992 releases, and 6 from releases in 1993.

Discussion

Release contribution to commercial fishery landings

Cultured fish from pilot releases in 1990–1993 made significant contributions to the commercial striped mullet fishery in Kaneohe Bay during 1993–1994. The substantial proportion of cultured fish in the bay-wide fishery in 1994 was surprising, given that these were pilot-scale releases of less than 100 000 individuals per year, and that released fish had direct access to the sea (striped mullet spawn in sea water (Blaber 1987), and nearly all cultured fish recovered were within the size range of mature adults). There was apparently low emigration of cultured fish out of the bay.

A similar release impact was apparent in a recreational mullet fishery in Hilo Bay, where small-scale hatchery releases comprised around 20% of the annual catch (Leber, Sterritt & Nishimoto unpublished data). The Hilo recreational fishery is almost entirely focused within an important striped mullet nursery habitat, which supports both juveniles and adults. The commercial fishery in Kaneohe Bay targets schools of striped mullet swimming throughout the bay. This study showed that cultured striped mullet released as juveniles could survive to maturity and recruit to the adult wild stock in habitats outside of juvenile nursery grounds.

These results indicate that relatively small-scale hatchery releases can make a significant contribution to local mullet fisheries in Hawaii. The data suggest that spawning stock biomass of the wild stock is quite low in Kaneohe Bay, and that releases of cultured juveniles could help increase adult population size.

Effectiveness of fishery survey technique

The creel survey approach used was successful in achieving the study objectives. However, a new approach was needed after intensive efforts in 1992 failed to yield adequate data from the quantitative roving creel census. Essentially, the modified survey method used after 1992 engaged experts to make *ad hoc* collections of the adult mullet population throughout Kaneohe Bay. With this modified approach, over 200 cultured, adult striped mullet were recovered from the fishery, and hatchery contributions to the fishery were documented with reasonably low levels of variability. By spring 1993, project biologists were working directly with cultured fish recovered by fishermen. This approach provided instantaneous counts of catch, a direct measure of effort, and an accurate estimate of CPUE (Phippen & Bergersen 1991).

There were several sources of bias in this study. CPUE and total effort data for the seven fishermen in 1993–1994 were biased in favour of relatively higher catch rates compared with those with less experience. The fishermen were expert at their trade and did not represent a cross-section of all mullet fishermen in Kaneohe Bay. Spring 1993 totals were biased (low) because it took about 4 weeks to identify fishermen and begin to gain their cooperation. During that time, some catches were missed. Spring was a peak fishing period, as effort was generally higher near the seasonal opening and closure of the fishery. Compared to direct samples of the catch by project biologists in the field, the fish-market data were subject to bias introduced by inevitable selling of part of the catch before arrival at the market to sample striped mullet. However, fish-market samples represented less than 22% of total fish sampled. Thus, the bias from incomplete catch estimates was restricted to a small portion of the data set.

Survival of cultured striped mullet

This study showed that recovery rates identified during the juvenile phase of the life cycle (Leber 1995; Leber *et al.* 1996a) were a reasonably good indicator of the effects of release strategies on survival patterns of adults. Consistent with the results from studies of juveniles, this study of adults showed: (1) a direct relationship between size-at-release and recapture rate after summer releases; (2) higher recovery of individuals < 70 mm when released in the spring, rather than summer, and zero recovery of fish < 60 mm if released in summer; (3) that release habitat had an important effect when fish were released away from the vicinity of their freshwater nursery habitats – shoreline releases near HIMB pier resulted in very poor (zero) recovery rates compared to releases in the vicinity of streams, regardless of size-at-release.

Such information about how release strategies affect survival and recruitment of cultured fish to adult cohorts is clearly needed to plan effective stock enhancement programmes (Peterman 1991; Cowx 1994; Blankenship & Leber 1995). These findings were consistent with other marine studies of SAR effects on recovery rates and survival (Tsukamoto *et al.* 1989; Svåsand & Kristiansen 1990; Ray, Stoner & O'Connell 1994; Willis, Falls, Dennis, Roberts & Whitchurch 1995) and release habitat effects on survival and dispersal (Stoner 1994; Iglesias & Rodríguez-Ojea 1994). Interaction of SAR effect with release season has not been shown with other marine species.

Some of the results based on adult fish recovered in this study were inconsistent with previous results from sampling juveniles. This study showed significantly lower recovery of fish released at the southern site, Kaneohe Stream, than at the northern site, Kahaluu Stream, and a trend for a direct effect of SAR on recapture rate after spring releases. By contrast, data for juveniles showed similar recovery from both stream sites, and recapture rate was not directly proportional to SAR following spring releases (Leber *et al.* 1996a,b).

The southern release site appeared to be a much poorer release site than previously recognized. This may reflect greater fishing mortality of sub-adults at the southern site, as there were numerous reports of mullet fishermen targeting the stream mouth at the southern site, but not at the northern site (unpublished data). The release-site effect was the clearest case where survival patterns of cultured striped mullet appeared to change between juvenile and adult stages of the life cycle (see Nordeide *et al.* 1994).

The lack of a clear SAR effect in the juvenile data set (following releases in the spring) may have been a consequence of gear bias from cast nets, which were used in the juvenile studies. Cast nets favour collection of smaller individuals and, thus, could mask a weak relationship between SAR and survival (Leber *et al.* unpublished data).

There was another difference between juvenile and adult data sets. In two pilot studies of juveniles, fish > 85 mm when released appeared to have better survival after summer releases than after spring releases (Leber *et al.* 1996 in press & 1996), whereas with the fishery data set, survival between seasons was similar for the > 85-mm SAR groups. Actual differences (between seasons) in survival of the larger fish released could be masked by variability in the fishery data. Alternatively, release season may affect whether survival patterns are determined mainly during the early juvenile stage (within a few weeks after release) or later in the life cycle.

Regardless of the above differences between juvenile and fishery data sets, this study showed that previous pilot studies of juveniles had provided early insight into important effects of release strategies on recapture rates of adults. Were these effects not understood, at least two situations could result in complete failure of hatchery releases in Kaneohe Bay. First, both the fishery and juvenile data sets showed a critical release size of 60 mm (the smallest size released that was subsequently detected in the fishery) following summer releases. Thus, summer releases of smaller juveniles or postlarvae have low probability of success.

Second, release site clearly regulates stocking success, as over 30 000 juveniles released outside of nursery habitats preferred by striped mullet (in three replicate lots in 1990) apparently suffered complete mortality. Hence, results from several release sites should be considered before selecting locations for full-scale releases. Pilot stock enhancement studies in other locations may benefit by expanding monitoring effort to include samples of juveniles (starting within a week or two after releases), if retrieving tags from fishermen is the primary approach for examining enhancement effect. Information gained from juveniles could be used to refine release protocols even before released fish enter the fishery.

Results from this study prompt another recommendation, for stock enhancement programmes that use internal coded wire tags. Even if money limits prevent having a structured net-sampling programme to retrieve coded wire tag data, a single technician working as an occasional crew member or observer on board commercial fishing vessels may afford the means to monitor stock enhancement results. That approach worked well in this study, where most tag data were retrieved, in effect, by engaging professional fishermen to sample adults in the striped mullet population.

Conclusions

This study showed clear potential to affect commercial fishery landings of striped mullet in Hawaii by releasing relatively small numbers of cultured fingerlings. These data:

(1) established that cultured striped mullet released as juveniles could survive, grow to maturity, and recruit to adult cohorts in the Bay, resulting in a significant percentage of cultured fish in the local fishery;

(2) confirmed most of the important findings from pilot studies (of juveniles) about effects of release strategy on recapture rates; this confirmation showed that most of the survival patterns that were affected by release strategy were established early in the juvenile stage and maintained through adulthood;

(3) suggested that the local striped mullet population is quite depleted.

Considering results from earlier pilot studies of juveniles, this study shows strong potential that full-scale hatchery releases would help 'enhance' the striped mullet population in Kaneohe Bay by increasing spawning stock biomass. Although 1993 showed the highest abundance of wild juveniles during 4-years of study (Leber *et al.* 1996), nursery habitat at the principal release site (Kahaluu stream) was well below carrying capacity for juveniles in 1993 and could support cultured fingerlings without displacing wild recruits (Leber *et al.* 1995). Thus, local abundance of adult striped mullet appeared to be limited by juvenile recruitment, which was increased by releasing cultured juveniles. Although there are few quantitative historical data, Shomura (1987) estimated that abundances of coastal fishes in Hawaii have declined 80% in the past century. If a careful approach is used to establish stocking criteria and to protect the wild stock (e.g. from loss of genetic diversity; transfer of disease organisms; displacement from overstocking and overfishing; see Cowx 1994 & related papers in Schramm & Piper 1995), then releasing cultured fingerlings should help to conserve and rebuild the depleted striped mullet population in Hawaii – that is, assuming that releases are used in conjunction with fishing regulations and habitat protection.

Cost/benefit comparisons are now needed to evaluate if hatchery releases are economically feasible to help increase yields in the commercial fishery on striped mullet. The value of replenishing a depleted stock, and of restoring the recreational fishery, needs careful consideration as well.

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