Influence of release season on size-dependent survival of cultured striped mullet, *Mugil cephalus*, in a Hawaiian estuary

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Abstract.—The concept that depleted populations of marine fishes can be revitalized by releasing cultured fish is being tested in Hawaii. In this study we evaluated effects of interaction between release season and size-at-release on recapture rates of cultured striped mullet, *Mugil cephalus*, released into Kaneohe Bay, Hawaii. Over 90,000 cultured *M. cephalus* fingerlings, ranging in size from 45 to 130 mm total length, were tagged with binary coded-wire tags. Half were released in spring, the remainder in summer. In both seasons, releases were made in three replicate lots. In each replicate, five size intervals of fish were released at two nursery habitats in Kaneohe Bay. Monthly cast-net collections were made in 6 nursery habitats over a 45-week period to monitor recapture rates, growth, and dispersal of cultured fish.

Recapture rate was directly affected by the seasonal timing of releases. Greatest recovery of the smallest fish released (individuals <60 mm) occurred following spring releases and coincided with peak recruitment of similar-size wild *M. cephalus* juveniles. In contrast, recovery of fish that were <60 mm at release was very poor after summer releases. Overall survival was similar at both release sites. We hypothesize that survival of released cultured fish will be greater when releases are timed so that fish size-at-release coincides with modes in the size structure of wild stocks. To optimize effectiveness of stock enhancement as a fishery-management tool, pilot release-recapture experiments should be conducted to evaluate effects of release season on size-dependent recovery of released animals.

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With world fisheries yields in steady decline (FAO, 1992, 1994; WRI, 1996), renewed interest in stock enhancement based on marine hatchery-releases is growing worldwide. This interest follows the demonstrated impact of stock enhancement in freshwater systems (e.g. Foerster, 1936; Solazzi et al., 1991) and is coupled with rapidly expanding marine aquaculture technology (Colura et al., 1976; Roberts et al., 1978; Øiestad et al., 1985; Lee and Tamaru, 1988; Eda et al., 1990; Forés et al., 1990; Tilseth and Blom, 1992; Honma, 1993; Main and Rosenfeld, 1994; Ostrowski et al., 1996).

An experimental and careful approach is needed to ensure that hatchery releases in marine systems result, at best, in successful supplementation or replenishment of marine fish populations, or, at least, in a better understanding of system uncertainty (Peterman, 1991; Blankenship and Leber, 1995). This approach should involve an initial research phase with pilot releases to explore the effectiveness of release strategies. Before initiating a test release to evaluate stock-enhancement potential in Hawaiian coastal environments, initial research was focused on a series of release experiments to determine which release strategies yielded greater survival of hatchery fish in the wild. This approach provided a more powerful field test of the marine stock-enhancement concept by using prior knowledge about the effects of 1) fish size-at-release, 2) release habitat, and 3) release season on growth and survival (Cowx, 1994; Blankenship and Leber, 1995; Leber et al., 1996).

Evidence is mounting that release habitat, season, and size-at-release, can substantially affect success of marine hatchery releases (e.g. Tsukamoto et al., 1989; Svasand

and Kristiansen, 1990; Stoner, 1994; Leber, 1995; Willis et al., 1995). Pilot releases have shown that survival rates following hatchery releases of striped mullet, *Mugil cephalus*, in Hawaii (Leber and Arce, 1996; Leber et al.[1]) and of queen conch, *Strombus gigas*, in the Caribbean (Stoner, 1994) were strongly affected by release habitat. Pilot releases with *M. cephalus* have also shown differential survival based on size-at-release. Pilot releases conducted during summer and fall in Maunalua Bay, Hawaii, (southern exposure) and during summer in Kaneohe Bay (eastern, windward exposure) have shown poor survival of cultured *M. cephalus* smaller than 70 mm total length (TL) at the time of release, compared with survival of larger-size individuals (e.g. 70 to 130 mm TL, Leber, 1995). In this study, we document a substantial effect of the seasonal timing of releases upon size-at-release–dependent recapture rates (number recaptured/number released) of cultured *M. cephalus*.

Materials and methods

Hatchery releases

Striped mullet were spawned at The Oceanic Institute in 1991 and reared to fingerling size. Batches of striped mullet eggs were hatched approximately every 5–6 weeks over a 5-month period and reared through three stages in cylindrical tanks. Larvae from each batch were hatched and cultured in 5,000-L conical-bottom tanks for 45 days. Stage-1 juveniles (i.e. postlarvae 45 days old, 20 mm total length [TL]) were transferred to 8,000-L tanks and reared for 40 days to stage-2 juveniles (i.e. the age and size at which we typically transfer fish out of nursery tanks into larger growout tanks, 85 days old, around 40 mm TL). Stage-2 juveniles were transferred to 30,000-L tanks and reared to tagging size (45 to 130 mm TL).

A factorial-design release-recapture experiment was performed to compare interactive effects of release season and fish size-at-release upon growth and survival of about 90,000 cultured striped mullet in the wild. During the period 5 May through 17 May 1991, and again from 12 July through 26 July 1991, juvenile striped mullet, ranging in size from 45 to 130 mm TL, were harvested from culture tanks and transferred to 40,000-L holding tanks. These fish were graded into five size groups, tagged, then released into Kaneohe Bay; half were released in May, the other half in July.

To identify experimental treatment conditions, all released fish were tagged with binary coded-wire tags (Jefferts et al., 1963). Tags identified release season, release site, size-at-release (SAR), release lot (date), and number of fish per treatment condition. Fish were tagged in batches, with a different code for each season-site and SAR-lot combination (2×2×5×3=60 batch codes). The five size groups released were 45–60 mm; 60–70 mm; 70–85 mm; 85–110 mm; and 110–130 mm TL.

Tags were implanted in the snout area with an automatic injector with head molds designed specifically for striped mullet. Previous studies have shown a coded-wire tag retention rate of 97% for striped mullet over a 6-month period (Leber, 1995). To verify tag-retention rates in this study, at least 5% of the fish tagged for each release lot were randomly subsampled prior to each release. The subsamples were retained in tanks for up to 6 months to check tag retention. Subsampled fish were not released.

Release statistics

During May and July 1991, 90,817 juvenile striped mullet were tagged and released into Kaneohe Bay. Numbers of fish released varied among size groups but were held nearly constant among release lots and between release sites and seasons (Table 1). At least 7,500 tagged fish were released in each of 12 release lots. There was size variation in all batches of mullet reared for this study. However, the primary difference among size-at-release groups was fish age.

For each season and SAR treatment combination, the experiment was replicated at two sites in Kaneohe Bay, and within each site, three replicate release lots were made (Table 1). The release lots were introduced into the bay over a 3-week period during both seasons (spring and summer). In each season, releases were made simultaneously at the inlets of two primary striped mullet nursery habitats, Kahaluu Stream and Kaneohe Stream. Kahaluu Stream is located in the north end of Kaneohe Bay (Fig. 1). This tributary is fed by several stream systems that originate in the Ko'olau mountain range. Kahaluu Stream expands into a lagoon about 300 m upstream. The mouth of Kaneohe Stream is 11.6 km southeast of Kahaluu Stream. Kaneohe Stream is also a Ko'olau mountain drainage system. Selection of release habitats in the vicinity of fresh-water tribu-

[1] Leber, K. M., D. A. Sterritt, R. N. Cantrell, and R. T. Nishimoto. In press. Contribution of hatchery-released striped mullet, *Mugil cephalus*, to the recreational fishery in Hilo Bay, Hawaii. *In* K. Lowe (ed.), Proceedings of the first biennial symposium for the Main Hawaiian Islands Marine Resources Investigation. Technical Rep. 96-01. Hawaii Department of Land and Natural Resources, Division of Aquatic Resources, Honolulu, HI.

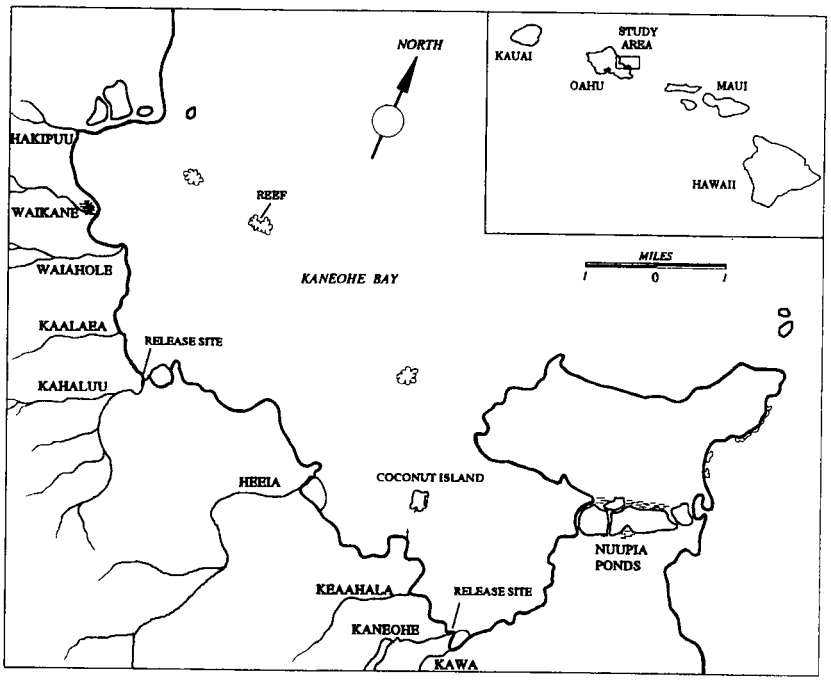

Figure 1

Map of the study area in Kaneohe Bay. Releases were conducted near the mouths of Kahaluu Stream and Kaneohe Stream. Recapture collections were conducted in streams throughout the Bay and on reef flats in the vicinity of stream mouths.

Table 1

Summary statistics for 90,817 striped mullet, *Mugil cephalus*, tagged and released in the 1991 pilot experiment to evaluate release-season effects on hatchery releases in Kaneohe Bay. Unique batch codes were used to identify fish from each cell in the matrix. Spring release lot 1 occurred on 3 May, lot 2 on 10 May, and lot 3 on 17 May. Summer release lot 1 occurred on 12 July, lot 2 on 19 July, and lot 3 on 26 July.

		Release season							
		Spring				Summer			
		Release lot				Release lot			
Release site	Size at release	1	2	3	Total	1	2	3	Total
Kahaluu Stream	45–60 mm	2,090	2,090	2,088	6,268	2,081	2,058	2,084	6,223
	60–70 mm	2,090	2,089	2,087	6,266	2,082	2,090	2,085	6,257
	70–85 mm	2,054	2,090	2,090	6,234	2,084	2,088	2,085	6,257
	85–110 mm	1,119	959	990	3,068	1,128	956	1,296	3,380
	110–130 mm	150	323	386	859	151	323	76	550
	Subtotal	7,503	7,551	7,641	22,695	7,526	7,515	7,626	22,667
Kaneohe Stream	45–60 mm	2,065	2,087	2,089	6,241	2,281	2,088	2,001	6,370
	60–70 mm	2,070	2,089	2,088	6,247	2,044	2,086	2,086	6,216
	70–85 mm	2,088	2,090	2,088	6,266	2,047	2,088	2,090	6,225
	85–110 mm	1,127	958	990	3,075	1,152	959	1,298	3,409
	110–130 mm	147	323	386	856	151	323	76	550
	Subtotal	7,497	7,547	7,641	22,685	7,675	7,544	7,551	22,770
Grand total		15,000	15,098	15,282	45,380	15,201	15,059	15,177	45,437

taries was based upon results from earlier releases (Leber, 1995; Leber and Arce, 1996; Leber et al.[1]) where release habitat appeared to be critical to survival.

All releases were conducted at about noon or early afternoon. The successive weekly release lots spanned the rising tide (lot 1 on a low tide; lot 2 on a rising tide; lot 3 on a low tide in both seasons). Releases were made near the shoreline in water from 0.5 to 1.5 m deep. There was a wider range of salinities at the southernmost site (Kaneohe Stream; Table 2).

Monitoring

Beginning 21 May 1991, we monitored abundances of hatchery-released and wild *Mugil cephalus* in Kaneohe Bay monthly for 11 months by sampling with cast nets. Recaptured tagged fish were removed from collections and returned to the laboratory for tag analysis. The first field collection after spring and summer releases began 2 weeks after the middle release lot (lot 2) was planted.

Each monthly collection was conducted over approximately a 2-week period. Collections were made at six nursery sites (sampling stations) within Kaneohe Bay. Collections were made for about an 8-hr period during the day at each sampling station. Stations were established in the vicinity of documented striped mullet nursery habitats at various tributaries located throughout the bay (Leber, 1995; six streams in Fig. 1: Waiahole, Kaalaea, Kahaluu, Heeia, Keaahala, and Kaneohe Streams).

To standardize collection effort, at each station two substations were sampled—one substation was established upstream, the other near the mouth of the tributary. Within substations, 15 cast net throws were made. To broaden the range of microhabitats and fish size-ranges sampled, two sizes of cast nets were employed. Ten of the 15 casts per substation were made with a 5-m diameter, 10-mm mesh net, and 5 casts were made with a 3-m diameter, 6-mm mesh net. Thus, a total of 180 casts were made each month.

Placement of net samples was stratified over observed schools of striped mullet juveniles. Completely random sampling in preliminary collections yielded few wild striped mullet and very few tagged individuals. Striped mullet schooled in fairly low densities within these clear-water nursery habitats, and our stratified-random collections targeted those schools. Nevertheless, the sample data used to determine proportions of tagged versus untagged mullet were randomly distributed because we had no a-priori indication that schools, once sighted, contained tagged individuals.

All striped mullet sampled were measured and checked for tag presence with a field-sampling detector (Northwest Marine Technology, Inc., Shaw Island, WA). Tagged fish were placed on ice and returned to the laboratory where the tags were recovered, and each fish was weighed and measured. Untagged fish were held at the field site in oxygenated water and then released after the 30 cast-net samples were completed.

Treatment identifications were made on the basis of the tags retrieved from recaptured fish. In the labora-

Table 2

Physical data recorded at the two release sites in Kaneohe Bay, Kahaluu Stream and Kaneohe Stream, for each release lot (release date) of striped mullet, *Mugil cephalus*. IN = incoming.

Season and release site (stream)	Release date	Tide stage	Secchi (cm)	Depth (cm)	Temperature (°C)		Salinity (‰)	
					Top	Bottom	Top	Bottom
Spring								
Kahaluu	5/03/91	IN 0.2'	51	59	33	32	11	12
Kaneohe	5/03/91	IN 0.5'	110	120	27	27	6	32
Kahaluu	5/10/91	IN 0.8'	70	75	29	26.5	15	27
Kaneohe	5/10/91	IN 1.6'	92	92	26	27	4	35
Kahaluu	5/17/91	IN 0.0'	25	40	29	29	24	26
Kaneohe	5/17/91	IN 0.0'	55	80	28	28.2	3	15
Summer								
Kahaluu	7/12/91	IN 0.8'	57	57	27.5	28	11	28
Kaneohe	7/12/91	IN 0.8'	75	122	27	27	11	35
Kahaluu	7/19/91	IN 1.6'	85	100	25.3	27	10	19
Kaneohe	7/19/91	IN 1.7'	115	115	26	27	4	35
Kahaluu	7/26/91	IN 0.7'	40	70	27.6	28	12	20
Kaneohe	7/26/91	IN 0.9'	65	90	26.2	26.5	6	34

tory, tags were located and extracted with a field-sampling detector. Tags were decoded by using a binocular microscope (at 40×). To verify tag codes, each tag was read twice (once each by two different research assistants).

Data were analyzed with Systat (Wilkinson, 1990). A randomized-block factorial analysis of variance (ANOVA) was used to compare means. Systat Basic was used to write tag decoding algorithms. For each recaptured fish, the algorithms identified batch size, release date (lot), release site, size-at-release, and release season from the tag codes identified in the laboratory. An error-check algorithm was also written to help identify errors that may have been made in reading tag codes. Variance estimates are expressed throughout as standard errors (with n=number of release lots).

Results

Tag retention

Tag retention in 4,799 individuals subsampled and held in tanks for six months averaged 98.6% (0.4% SE). With one exception (92.4%), all retention rates within release lots exceeded 97%. No significant tag loss was observed in any group later than 1 month after tagging. This is a normal tag loss rate for coded-wire tags (Blankenship, 1990).

Recapture summary

Of the fish released, 2,511 cultured striped mullet were recaptured in monthly cast-net samples at nursery habitats. Based on the 98.6% average tag retention rate, the number of cultured fish recaptured can be extrapolated to 2,546, or 2.8% of the fish released. About 6.6% (166) of the tags taken from the 2,511 recaptured fish were lost during extraction.

Total number of tagged fish in samples decreased over the 11-month monitoring (Table 3) but was fairly constant during the last 7 months of the study (when numbers of tagged fish ranged from 49 to 134 individuals). Total number of tagged fish collected was greater at Kaneohe Stream. However, this pattern varied considerably from month to month, and most of those fish were collected within 1 month after the May and July releases.

Tagged fish represented between 8% and 48% of the striped mullet captured in monthly samples (from all stations combined; Table 3). Percentage of cultured fish in samples was greatest at Kaneohe Stream, where contribution rates declined from 76% following the May release to 41% by the end of the study. Although numbers of tagged fish collected at Kahaluu Stream were often similar to those for Kaneohe Stream, there were always greater numbers of wild fish in collections at Kahaluu Stream (Table 3).

Impact of release season

Recapture rates and contribution rates When size-at-release was not considered, the contribution of cultured fish to recruitment appeared to be unaffected by release season. Release season had no significant effect on mean recapture rates over time (ANOVA, $P>0.54$, data from all size-at-release intervals combined). After 3 months in the wild, mean numbers of cultured fish in samples varied between

Table 3

Numbers of wild and hatchery-released striped mullet, *Mugil cephalus*, recovered in cast-net samples made in Kaneohe Bay. Proportions of hatchery fish were determined by the presence of a coded wire tag.

		1991								1992					
Collection site	Source	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total	Mean	Standard Error
All stations in Kaneohe Bay	Wild	985	1,099	1,439	453	659	722	952	550	824	864	310	8,857	805.2	95.7
	Hatchery	912	194	551	184	101	117	134	76	116	77	49	2,511	228.3	79.9
	% Hatchery	48.1	15.0	27.7	28.9	13.3	14.0	12.3	12.1	12.3	8.2	13.6		18.7	3.5
Kahaluu Stream (Release site in N. Kaneohe Bay)	Wild	265	201	303	137	260	318	331	158	350	184	134	2,641	240.1	24.3
	Hatchery	184	122	237	25	20	56	91	25	46	15	18	839	76.3	22.7
	% Hatchery	41.0	37.8	43.9	15.4	7.1	15.0	21.6	13.7	11.6	7.5	11.8		20.6	4.1
Kaneohe Stream (Release site in S. Kaneohe Bay)	Wild	207	87	264	88	44	85	115	52	85	87	41	1,155	105.0	20.9
	Hatchery	653	64	270	135	43	52	35	45	55	45	28	1,425	129.5	56.5
	% Hatchery	75.9	42.4	50.6	60.5	49.4	38.0	23.3	46.4	39.3	34.1	40.6		45.5	4.2

about 10 and 27 individuals per release lot throughout 36 weeks (Fig.2). However, as shown below, recapture rate was in fact dependent upon the interactive effect of release season and size-at-release. (Note: for evaluating the effect of release-season, data can be compared only through weeks 35 or 36 following releases, the length of time fish were monitored after summer releases; by the end of the study, fish released in the spring had been in the wild for an average of 45 weeks, 10 weeks longer than those released in summer.)

Dispersal patterns There were no clear seasonal trends in dispersal patterns. Cultured striped mullet showed a strong tendency to remain in the vicinity of release sites, regardless of release season or size-at-release. Few of the 2,511 tagged fish recovered in samples had moved into other nursery habitats in the bay. The only significant movements observed were from release habitats into the streams located immediately to the north of each release site (Table 4). This pattern was repeated after spring and summer releases. There were isolated cases of fish moving from one release habitat to the other, as well as movement from release habitats into other nursery habitats in the bay. But the magnitude of dispersal out of release habitats and beyond the streams immediately north of those sites was negligible. Overall, 90.8% ± 3.1% (SE) of the cultured fish collected through 36 weeks in the wild were recovered at the nursery habitats into which they had been released.

Growth Growth after spring releases was similar to growth following summer releases. Length increase following releases is plotted in Figure 3 for fish from the 70–85 mm treatment group, which was representative of all 5 size-at-release groups. There was little change in mean length during winter months (from September 1991 through February 1992; weeks 20–45 following spring releases in Fig. 3).

Release season effect on recapture frequencies among size-at-release groups Recapture frequencies ([number recaptured / number released] × 100%) within size-at-release intervals revealed an obvious

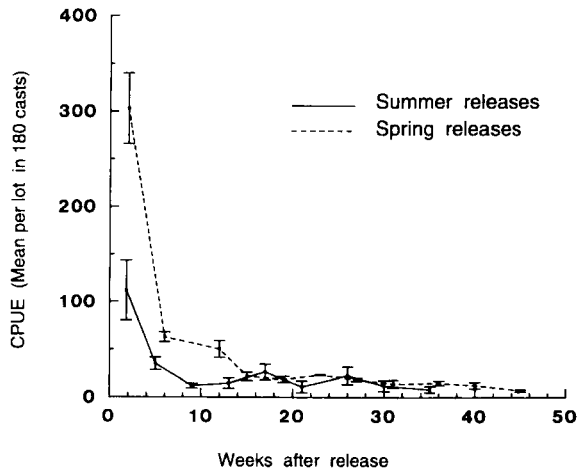

Figure 2

Mean number of tagged cultured fish in samples following spring and summer releases into Kaneohe Bay. Data are means per release lot (± standard error [SE]; n = 6 lots per season [3 at each release site]).

Table 4

Movement patterns following 1991 releases in Kaneohe Bay. Release season and release site are identified for tagged fish recovered at the various collection (recapture) sites throughout the Bay. Recapture sites (and distances travelled) are ordered geographically within collection dates, from the northernmost site (Waiahole Stream) to the southernmost site (Kaneohe Stream) at which tagged fish were collected (see Fig. 1). Totals for spring releases represent those through week 36; totals for summer releases are those through week 35. To compare results between release seasons over a similar time frame, data are excluded for weeks 40 and 45 after spring releases.

Release season and recapture site	Kahaluu Stream		Kaneohe Stream	
	n	Distance (km)	n	Distance (km)
Spring release				
Waiahole	1	3.05	0	15.00
Kaalaea	92	0.98	0	12.59
Kahaluu	509	0	1	12.04
Heeia	0	5.55	1	5.88
Keaahala	0	10.61	31	1.08
Kaneohe	1	11.58	947	0
Total	603		980	
Summer release				
Waiahole	0	3.05	0	15.00
Kaalaea	14	0.98	0	12.59
Kahaluu	298	0	0	12.04
Heeia	0	5.55	0	5.88
Keaahala	1	10.61	57	1.08
Kaneohe	0	11.58	392	0
Total	313		449	