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CONTENTS

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AN INNOVATIVE TECHNIQUE FOR SEEDING ABALONE AND PRELIMINARY RESULTS OF LABORATORY AND FIELD TRIALS [1]

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In recent years the California abalone fishery has undergone a severe decline. However, present technology provides an opportunity to test rehabilitation and enhancement techniques for this valuable fishery resource. Because the biology and technology for producing and cultivating abalone is well developed, sufficient quantities of juvenile abalone are available for seeding programs. Previous efforts to rehabilitate once productive abalone fishing grounds have failed, met with limited success, or have been of questionable value. These enhancement efforts were conducted by divers who generally hand-planted the abalone in assumed optimal habitat areas. This method is not only unwieldly and labor intensive; but the planted abalone are generally stressed, and often are highly vulnerable to predators. In an effort to rectify this problem a new abalone planting method has been designed, tested and appears promising. This method employs a "seeding module" which is designed to serve as an intermediate habitat for the abalone, and retains them for a predetermined acclimation time prior to their release and dispersal. Evaluation of this technique indicates that site selection and abalone size are critically important factors. However, if the appropriate criteria are met then high abalone survivorship and an enhanced fishery resource could result.

INTRODUCTION

The red abalone, *Haliotis rufescens,* ranges from central Baja California to southern Oregon (Cox 1962) and is extensively sought by sport and commercial fishermen. Commercial landings of red abalone have exhibited a steady decline in recent years. In 1967 nearly 1,228,000 kg of red abalone were landed, however, by 1986 the catch had dwindled to 120,000 kg (Calif. Dept. of Fish and Game, landing receipts). Historically, during the peak production years, the major commercial fishing grounds for red abalone were located along the central California coast from Monterey to Point San Luis. Morro Bay represented the center of the fishery and the majority of the catch, exceeding 450,000 kg annually, was landed there (Cox 1962, Miller 1974, Burge and Schultz 1973). This fishery persisted through the 1960's and into the early 1970's (Miller 1974, Burge, Schultz, and Odemar 1975). The demise of the central California fishery was due to the sea otter, a major predator of abalone (Ebert

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1968a, b, Burge and Schultz 1973, Miller 1974, Burge et al. 1975). Presently, no red abalone are taken commercially from the central California coast, nor are any landed at Morro Bay.

Red abalone populations have declined elsewhere in California principally due to human-related factors such as over-exploitation and habitat degradation (Burge et al. 1975, Tegner et al. 1981, Hardy, Wendell, and DeMartini 1982). A limited entry commercial abalone fishery and further restrictions on the sport fishery were instituted in 1976 (Hardy et al. 1982, Schultz 1984).

To augment this valuable but declining resource the California Department of Fish and Game (CDFG), university scientists, and commercial abalone fishermen have conducted various enhancement projects (Cox 1962, Ebert and Houk 1984, Tegner and Butler 1985). Enhancement efforts included the seeding of small sized hatchery-reared abalone or of transplanting mature adult stocks. Unfortunately, although relatively large numbers of abalones have been seeded or transplanted in California, on an experimental basis, their survivorship, and ultimate contribution to the resource has been difficult to assess (Tegner and Butler 1985). Therefore, abalone seeding and transplanting as a means to enhance the resource remains questionable from a biological standpoint.

In general, previous efforts to seed small abalone for population enhancement, in California, were conducted by divers who hand-planted the abalone into rocky crevices or artificial habitats (e.g. concrete blocks). More recently, to reduce handling stress seed abalone were put on adult shells (i.e. abalone, oyster, scallop) and hand-planted. These methods were not only unwieldy and labor intensive but the abalone may have been stressed by handling, and as a consequence, more vulnerable to predation before acclimating to their new environment. These factors served as an impetus for us to develop a more efficient approach to seed small sized abalone. Herein we describe an innovative, expedient method to transport and seed relatively large numbers of small abalone that can acclimate in an intermediate habitat (seeding module), free from predation, preparatory to dispersal into the natural environment. Abalone dispersal rates and movement patterns from the seeding module, and short-term behavior and survivorship are also described for laboratory tests and a field trial.

METHODS AND MATERIALS

Abalone Seeding Module Design and Operations

The seeding module consists of a concrete utility box, commercially available, that is commonly used in water and gas meter applications. The utility box dimensions are 70 × 46 × 30 cm high (Figure 1). It was modified by adding a 5 cm thick concrete base, and by cutting-out a 5 × 22 cm section at each end to provide abalone egress. A PVC casement was fitted around both of these passageways using 0.6 cm thick PVC 90° angle stock that was glued directly to the concrete. These passageways were partitioned into four openings, each measuring 5 × 4 cm high, using 0.6 cm thick PVC strips. These partitions serve to restrict large predators from entering the seeding module, yet allow egress of abalones up to 6 cm in length.

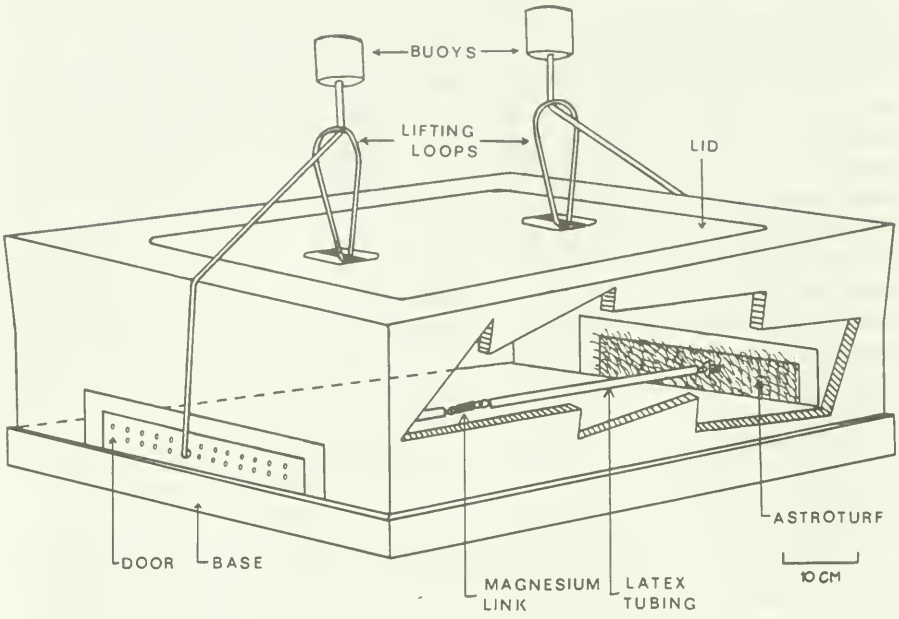

FIGURE 1. The abalone seeding module with cut-away section showing the temporary door interior with Astroturf, and the magnesium link attachment.

Temporary doors were fitted in both passageways using 0.6 cm thick perforated PVC plastic sheeting and were 30 × 8 cm high. Astroturf was cemented to the door interiors to inhibit abalone attachment. Thereby the abalone could not impede water circulation by covering the door perforations, nor could they block the doors from opening by adhering to the door jambs.

Both doors were held in place under tension (~ 60 newtons), with two 20 cm lengths of latex rubber tubing. This was done by fastening one end of each tubing length to opposite doors, then pulling the "free" ends of the tubing lengths together, and innerconnecting them with a magnesium link. Plastic cable ties were used to fasten the tubing ends to the doors and the magnesium link. The dissolution rate of magnesium in seawater is a function of temperature and salinity. Foreknowledge of these two parameters enabled us to select a proper sized link. Dissolution of the magnesium link in seawater ultimately releases the doors. A buoy was attached to each door exterior via a 0.6 cm diameter nylon line 0.5 m long. Between the buoy and door the nylon cord passes through a nylon lifting loop that is attached to the lid (1 lifting loop/buoy). When the doors are released they float up, away from the module passageway, and are retained by the lifting loops (Figure 1). The temporary doors are installed just before the abalone are introduced to the seeding module.

Abalone Collector-Transporter

An abalone collector-transporter was designed and fabricated to provide an attachment surface for the abalone while in transit and in the seeding module.

The collector-transporter was made from four, 50 cm long PVC pipe sections, of four diameters (10, 15, 20 and 25 cm), that were cut in half lengthwise. These were stacked one directly above the other (smallest diameter pipe on the bottom), and fastened together near either end using 2 × 13 cm PVC bolts. This configuration provided about a 2 to 3 cm space between each pipe section for the abalones (Figure 2). Astroturf was affixed to the collector-transporter base. This served two purposes; (i) it prevented abalone from adhering to the base whereby they could be crushed when the collector-transporter was positioned in the seeding module following transit and (ii) it presented a good friction surface with the concrete. This minimized the shifting of the collector-transporter in the seeding module, particularly when subjected to severe seawater surge conditions, and thus reduced potential damage to the contained abalone. The abalone collector-transporter was designed to accommodate 500 to 1000 juvenile abalone of 15 to 30 mm shell lengths. A seeding module accommodates only one collector-transporter.

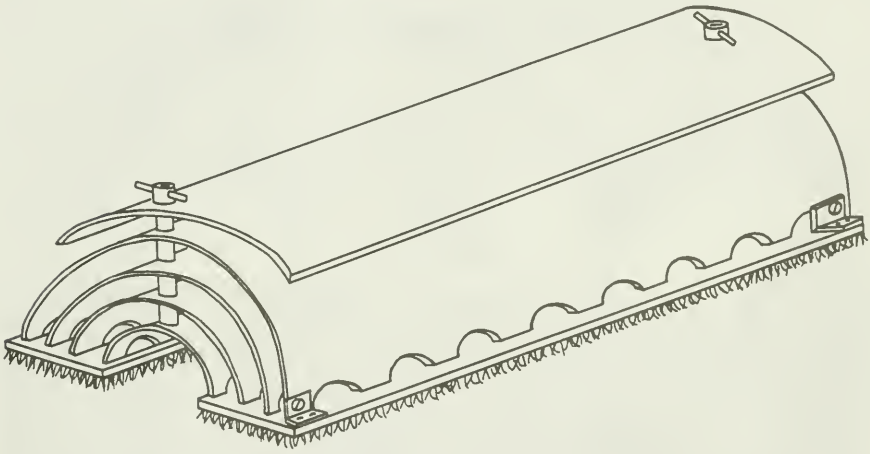

FIGURE 2. The collector-transporter used for translocating abalones from the laboratory to the field. Not to scale. Dimensions, overall, are 50 × 31 × 19 cm high.

Abalone Species Selection and Shell Color

The red abalone was selected for testing because it was readily available, economically is the most valuable to the fishery resource, and because stocks have been seriously depleted in some areas. The animals used for this study were hatchery-reared and supplied by the CDFG, Marine Resources Laboratory, Granite Canyon (MRL).

It is well known that diet influences the shell coloration of abalone (Leighton 1961, Olsen 1968). Since the hatchery-reared abalone used during this study were fed predominantly giant kelp, *Macrocystis* spp., their shell color was typically aquamarine. By contrast, native red abalone typically exhibit a sepia shell color. Therefore, the shell coloration of hatchery-reared abalone used for this study served as a useful "tag" for field identification from the natural population, and also could be used for subsequent growth rate information.

Laboratory Studies

Laboratory studies with the abalone seeding module were conducted in a circular, 2.4 m diameter, fiberglass tank. Ambient temperature seawater (12–15°C) was provided. To simulate the natural environment, cobbles and boulders, with attached biota, were distributed on the tank floor. Additional substrate consisted of four hollow concrete blocks that were spaced equidistant around the tank floor perimeter. Sand patches fronted each concrete block, and giant kelp fronds were anchored to two of the concrete blocks. This arrangement of substrates and kelp (Figure 3) was used to determine abalone dispersal patterns, substrate preferences, and the influence of forage (kelp).

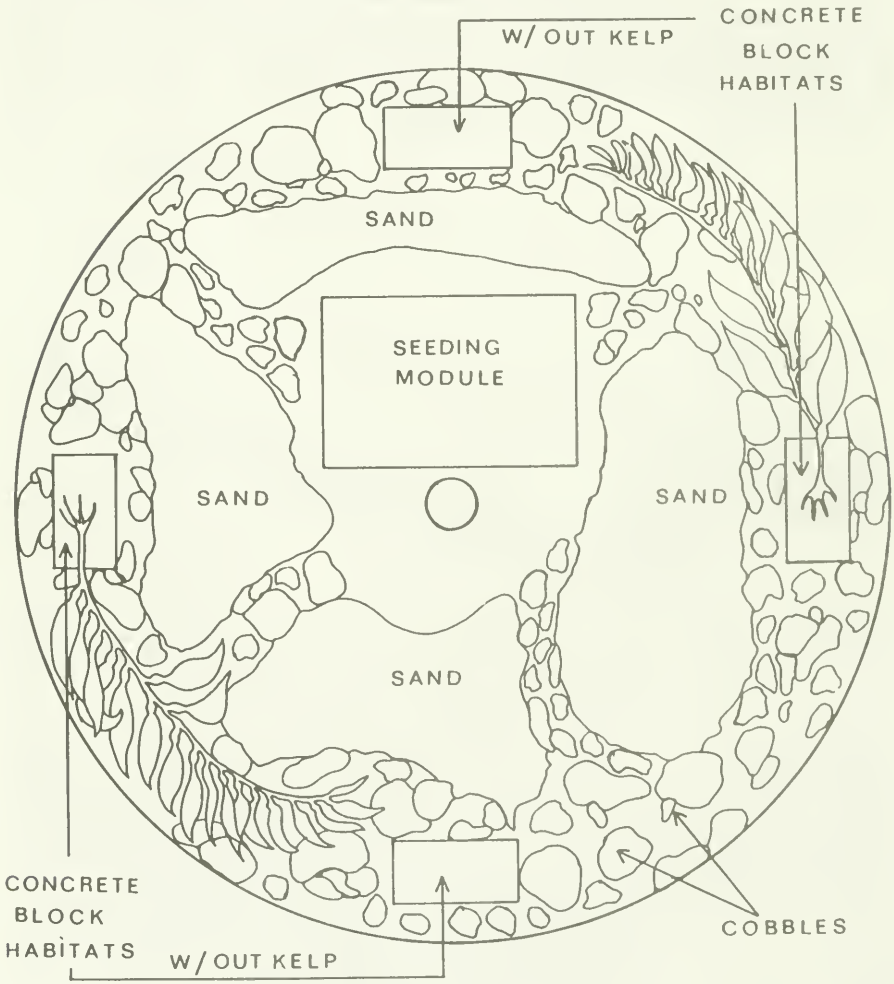

FIGURE 3. A schematic diagram of the 2.4 m diameter tank floor layout used to measure abalone dispersal rates and patterns.

Two abalone size groups were used, with one exception, for laboratory trials. These averaged 10 mm (range=8–12 mm), and 20 mm (range=18–22 mm) shell lengths, and 250 of each size group were used per trial. The one variant abalone size group trial comprised 554 individuals with a mean length of 32 mm (range=24–45 mm). The abalone used for all trials were first contained and acclimated in the seeding module through 2 nocturnal periods. A magnesium link size was selected that would decay, separate, and release the seeding module doors in the late afternoon-early evening period, just prior to the third nocturnal period of abalone containment. This release time was selected because it corresponds to a known rise in abalone activity that has been observed in laboratory and field populations.

An initial series of seven trials were made in the tank to measure abalone dispersal rates and movement patterns from the seeding module according to abalone size. They spanned 1,2,2,4,5,7 and 8 nocturnal periods post-abalone release. The second 2 day release period (noted above) was conducted for the larger abalone size group ($\bar{x}=32$ mm). All abalone were recovered at the end of each trial and their location plotted diagramatically on a data sheet.

Following the initial series of trials a longer term trial (28 days) was conducted. Only the 10 mm and 20 mm mean length abalone size groups were used for this trial; 250 of each size group. The tank was drained daily and all abalone were counted according to size and location inside and outside of the seeding module for the trial duration. This trial was duplicated using two "fresh" abalone size groups.

Field Studies

Field studies were conducted in Carmel Bay, California (lat 36°34'N, long 121°56'W). These studies were designed principally to compare abalone behavior and survivorship according to seeding method and abalone size. The study area was comprised of two sites 50 m apart, in 7 m depths. Each study site area was circular and encompassed about 28 m^2. A 3 m radius line was used to delimit each study site. An abalone seeding module was placed at one site, while the other site (control) lacked a seeding module. Abalone seeded at the control site were allowed to attach to adult abalone shells in the laboratory, about 10–15 per shell, transported to the control site where the shells were hand-planted in rock crevices. The abalone collector-transporter was used to hold and transport abalone to the seeding module.

The biota in the general study area was characterized with respect to abalone ecology. *Macrocystis* was the major canopy forming algae present, and is important nutritionally for abalone. Predominant phaeophytes in the understory were *Laminaria* spp. and *Pterygophora californica* while *Botryoglossum farlowianum, Gigartina* spp. and *Rhodymenia* spp. were the most conspicuous rhodophytes. Articulated and crustose coralline algae were major turf components.

Known juvenile abalone predators in the general study area, although not necessarily documented during surveys, included the cabezon, *Scorpaenichthys marmoratus;* crabs, *Cancer* spp.; *Loxorhynchus crispatus, Paguristes* spp.; various sea stars, *Pisaster* spp., *Orthasterias koehleri,* and *Pycnopodia helianthoides;* and octopuses, *Octopus* spp.

To assess the octopus population, traps were designed, fabricated and deployed. These consisted of PVC pipe sections, about 36 cm long, of three diameters (about 2.5, 3.8 and 5.1 cm), capped at one end, with a coupling inserted near the capped end to facilitate octopus removal. Three traps, one of each size, were deployed at each study site.

One field trial was conducted using 1000 abalone of two size groups accordingly:

Abalone size group and no. of abalone

Site	*10 mm (range = 8–12 mm)*	*20 mm (range = 18–22 mm)*
Control	250	250
Seeding module	250	250

The abalone were transported from the laboratory to the study site, out-of-water, in styrofoam containers following procedures developed at the MRL. These consist of putting the abalone and their substrates (adult abalone shells or collector-transporter) in a plastic bag, adding seawater moistened sponges, filling the plastic bag with pure oxygen and sealing it. One or two refrigerant bags (BLUE ICE®) are placed on the bottom of each chest, followed by 5–6 layers of newspaper to insulate the abalone from close contact with the refrigerant. Transit time from the laboratory to the study site, and placement of the abalone in the seeding module was about 2 h.

Field observations began two days after the abalone were seeded, just prior to the separation of the magnesium link in the seeding module. A second survey was made just following magnesium link separation and door release. Observations were made at both sites weekly thereafter with a minimum of distrubance. These surveys included, (i) a general qualitative assessment of the biota, (ii) qualitative and quantitative observations of abalone distributions and dispersal patterns, (iii) removal of dead abalone (empty shells) and noting when possible, the cause of mortality, (iv) opening the seeding module lid to determine abalone dispersal rates and to check for abalone predators, and (v) examination of octopus traps. Four weeks post-release both sites were destructively surveyed. This entailed thorough examination and disturbance of all abalone habitat, where physically possible, throughout the 28 m^2 study site. All live abalone found were noted according to position and examined for growth. A less intensive extralimital survey was made for seeded abalone that extended out to approximately 10 m from each site reference point. This survey focused on areas with turnable rocks (15 cm diameter and larger), because they are a preferred habitat of cryptic abalone in the area.

RESULTS

Seeding Module Performance

The seeding module performed well during laboratory and field trials. Magnesium links separated as planned, and the buoys lifted the doors clear of the module passageways on all trials. The configuration and weight of the module enabled it to remain stable at the relatively shallow depth of the study site, even during moderately strong surge conditions. Seawater quality inside the seeding module apparently was adequate for the abalone since there were no

mortalities or evidence of stress. The grate affixed to the door passageway was sufficient to preclude observed abalone predators, yet there was no evidence that abalone egress from the module was inhibited.

The abalone collector-transporter proved to be an efficient method to collect, hold, and transport abalone to the seeding module. Abalone readily crawled on the collector-transporter when it was placed in a laboratory tank containing abalone, and there were no mortalities during the 2 h transit (out-of-water) period, for the field trial.

Laboratory Trials

Initial Trial Series

Fifty percent or more of all abalone size groups had left the seeding module following two nocturnal periods (Table 1). A direct relationship was evident between abalone size and dispersal rate from the seeding module. The largest abalone size group ($\bar{x}=32$ mm) traveled further, faster, than other size groups. The smallest abalone size group ($\bar{x}=10$ mm) dispersed the slowest.

TABLE 1. Dispersal Of Red Abalone From The Seeding Module, During Laboratory Trials, N (%).

Size group (mm)	*No. seeded*	*Nocturnal periods and abalone, n (%), found outside seeding modules following release*							
		1	*2*	*4*	*5*	*7*	*8*	*28*	*28*
10	250	96(38)	143(57)	176(70)	184(74)	180(72)	152(61)	220(88)	232(93)
20	250	130(52)	127(51)	200(80)	149(60)	235(94)	215(86)	230(92)	248(99)
32	554		281(51)						

The two larger abalone size groups preferred the concrete blocks with kelp rather than the blocks without kelp (Table 2). Observations of the largest abalone size group revealed that following two nocturnal periods post-release, 281 (50.7%) were outside the seeding module, of which 143 (50.9%) were observed on the concrete blocks with kelp, while only 10 (3.6%) were observed on the concrete blocks without kelp. This preference of the larger size abalone for concrete block habitats with giant kelp progressively increased with time. By contrast, the smallest abalone size group ($\bar{x}=10$ mm) was not observed on concrete blocks until seven nocturnal periods had elapsed, and very few were present (Table 2). All abalone size groups formed clumped distributions, irrespective of habitat type.

TABLE 2. Number of Red Abalone Observed On Concrete Block Habitats With And Without Giant Kelp.

Size group (mm)	*Nocturnal periods and no. of abalone on habitats (kelp/no kelp) following release*							
	1	*2*	*4*	*5*	*7*	*8*	*28*	*28*
10	0/0	0/0	0/0	0/0	2/2	2/0	19/9	24/13
20	14/0	20/2	32/6	34/5	65/7	56/6	63/13	89/15
32		143/10						

Second Trial Series

Abalone dispersal rates from the seeding module compared closely with the first trial series through eight nocturnal periods. Also, no significant difference was apparent between the duplicate test runs (comparison of simple linear regressions, $0.1 < P < 0.2$). Following release of the doors from the seeding module passageways, the exodus of abalone was initially high, then leveled and remained at a uniform rate (Figure 4). After 14 nocturnal periods post-door

release approximately 50 abalone remained in the module, but very few were on the collector-transporter and it was removed. Also, it became evident through day-to-day counts that some abalone that had left the module returned.

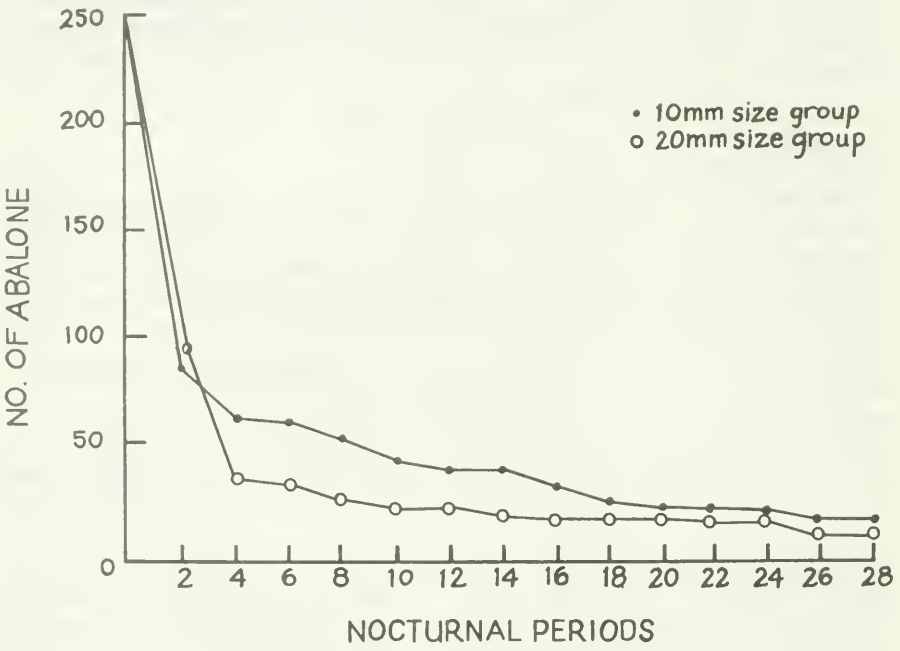

FIGURE 4. Dispersal rate of the red abalone from the seeding module during laboratory trials.

Observations made three nocturnal periods after the doors were released revealed a correlation between abalone movement and photoperiod. Sightings made at midday (1200 h and bright sun), 1.5 h before sunset, at sunset, and 45 min. later revealed 2,8,41, and 150 emergent abalone, respectively. Also, observations made at sunset and later revealed a high activity level for the emergent abalone as they traversed the rock substrate.

Field Trial

This trial was conducted during the summer (August–September) period when algal assemblages in Carmel Bay typically attain maximum seasonal lushness (Foster and Schiel 1985). Sea surface temperatures averaged 13.7°C. The octopus traps were examined, at each site during each survey, but no octopuses were caught.

Seeding Module Site

When the collector-transporter and contained abalone seed was placed in the seeding module no conspicuous abalone predators were observed within 3 m of it. Also, abalone predators were not observed just prior to, and immediately

following door release. Only one masking crab, *L. crispatus,* was found within the study site during the trial. Weekly observations revealed that the abalone left the seeding module at a rate comparable to that documented during laboratory trials. After 4 weeks no abalone remained in the seeding module. Prior to the destructive survey, abalone were observed under rocks and in crevices at distances up to 10 m from the seeding module. After 4 weeks at liberty 178 live abalone, comprised of almost a 50:50 size group ratio, were located (Table 3). The majority of these abalone were evenly distributed out to 3 m from the module. A cursory survey beyond the site limits uncovered one 20 mm size group abalone about 8 m from the module. In general, most abalone were found under rocks that were 15 cm and larger in diameter. All but six of the abalone (five 10 mm and one 20 mm size group) exhibited recent shell growth. Very few empty shells were found (Table 4).

TABLE 3. Live Red Abalone Recovered, Percent Showing Shell Growth, And Percent Unaccounted For, After Four Weeks, From The Field Study Sites In Carmel Bay.

	Size	*Live abalone*		*New shell*	*Abalone*
Site	*group (mm)*	*no.*	*%*	*growth (%)*	*unaccounted (%)*
Seeding	10	87	34.8	94.3	64.4
module	20	91	36.4	99.6	61.2
Control	10	26	10.4	34.6	84.8
	20	81	32.4	84.0	50.4

TABLE 4. Red Abalone Mortalities Recovered During Weekly Surveys At The Field Study Sites In Carmel Bay.

	Abalone size	*Shell recoveries (no./condition *)*				
Site	*group (mm)*	*week 1*	*week 2*	*week 3*	*week 4*	*total*
Seeding	10	0/—	0/—	0/—	2/I	2
module	20	2/I	0/—	1/F	2/F	6
				1/I		
Control	10	2/I	3/I	2/I	5/I	12
	20	2/I	2/I	2/I	5/F	
		8/F	2/CE	3/CE	8/I	
					11/CE	43

* I=intact, F=fragment, CE=chipped edges

Control Site

No obvious large abalone predators were observed while seeding the abalone, although small crabs (eg. *Paguristes* spp., and *Mimulus* spp.) were seen. However, 2 days post-abalone seeding two *L. crispatus* and one *P. brevispinus* were observed at the site but not removed. Shell fragments of two 20 mm size group abalone were observed along with the majority of the live seeded abalone still attached to the adult abalone shells that had served as their seeding substrate. A cursory examination of the undersides of several smaller rocks that were adjacent to the seeding substrates revealed several clumps of seeded abalone.

During each weekly survey predatory sea stars were observed within the study site. Additionally, a cabezon was seen on one occasion and masking crabs were common. Many of the seed abalone appeared to remain on the shells used as a planting substrate for the duration of the study. After 4 weeks at liberty 107 seed abalone were located and marked with a grease pencil (Table 4).

Most abalone (97%) were found on the original planting shells or next to them, while no abalone were found beyond the study site limits. In comparison to the seeding module site, a smaller percentage of both seed abalone size groups showed growth. Surveys disclosed a greater number of empty shells at this site compared to the seeding module site (Table 4). These mortalities were typically found where they had been planted.

DISCUSSION

Abalone seeding projects in California, prior to this study, generally required too many divers who expended considerable time and effort hand-planting abalones. This resulted in disturbance of the physical habitat at the seeding site, and frequently attracted abalone predators (Fox and McMullen, unpubl. data; Tegner and Butler 1985). The use of "mother" shell (adult abalone, scallop or oyster shells) as an attachment surface for seed abalone did serve to reduce seeding time and effort, and probably stress on the abalones. Data compiled from several CDFG Cruise Reports show that an average of 529 abalone were seeded per diver h (range = 200–1027). This average coincides with the time (1 h) needed to seed 500 abalone at the control site. In contrast, we seeded 500 abalone in 5 diver min in the seeding module, with a minimum of site disturbance, and without attracting predators. Moreover, this seeding rate can be increased several fold simply by increasing the seeding module size and number of contained abalones.

The abalone containment period in the seeding module prior to door release (minimum of 48 h) was arrived at through deductive reasoning and seems satisfactory. We hypothesized that this time period was sufficient for the abalone to acclimate, and a lack of forage (kelp) would serve to hasten their departure from the module. This starvation period, based on laboratory observations, would not cause stress. No tests were performed at shorter or longer durations and it is possible that some other containment duration could prove more optimum.

There is strong evidence from laboratory and field observations (pers. obser.), and reinforced by this study, to indicate that twilight (early evening) is an optimum time for seeding module door release and abalone dispersal. The abalone activity level sharply increases at this time and does not diminish until just before dawn.

Initially we were concerned about possible poor water circulation within the seeding module, particularly during laboratory trials, where water flow rates were considered low. However, there was no evidence of hypoxic conditions (no stressed or dead abalone). This suggested that the seeding module possibly could accommodate a greater abalone density. We confirmed this by routinely holding 1,000 red and pink abalone, *H. corrugata,* averaging about 20 mm long, in a seeding module with a collector-transporter. These were 48 h tests, performed in the laboratory, and without any abalone mortalities.

During laboratory and field trials the dispersal rate of abalone from the seeding module appeared to be fairly rapid. For example, during laboratory trials approximately 50% of all abalone had left the seeding module following two nocturnal periods. Initial field observations disclosed that after one week post-release only 11% of the abalone remained. The results of all laboratory and field trials showed that 90% or more of all abalone had left the seeding module

within two weeks. Most abalone observed in the seeding module after two weeks exhibited growth, which suggests that these individuals used the module as a habitat and foraged outside nocturnally.

Fox and McMullen (unpublished data) found that potential abalone predators were attracted to the seeding area while the abalones were being seeded, and observed predation of just-seeded abalones. Tegner and Butler (1985) noted that abalone predators rapidly returned to an abalone seeding area following their removal, and that seeded and hence stressed abalones, were also vulnerable to the whelk; *Kellettia kelletti.* This whelk does not prey on healthy abalone. It was clearly evident from our field study that the control site abalone attracted predators. In contrast, the abalone seeded at the module did not attract obvious potential abalone predators, or other reef fauna during the field trial; either before or after door release.

The more rapid egress and dispersal of the larger size group (20 mm) abalone from the seeding module during laboratory trials and their preference for concrete blocks with kelp was not unexpected. Momma et al. (1980) and Miyamoto et al. (1982) reported that larger abalone seed sizes dispersed more rapidly. The 20 mm size abalone probably were attracted to the blocks with kelp because they prefer macroalgae, while their smaller size cohorts ($\leq$ 15 mm) prefer a diatom diet; and a diatom film covered most exposed surfaces.

Principally, we tested two abalone size groups to compare dispersal rates from the seeding module and survival. Underlying these tests was the obvious and direct implication to the economics of seeding abalone for fishery enhancement (i.e. cost effectiveness). It requires about six months to cultivate red abalone to 10 mm shell lengths, and another five months for them to attain 20 mm lengths. There is a direct relationship between seed size and cost. The main objective is to optimize abalone seed size with survivorship. Some investigators report better abalone survival at larger seed sizes (Inoue, 1976; Momma et al., 1980; Miyamoto et al., 1982). But, Tateishi et al. (1978) found a survival rate of 48.6% nine months after abalone averaging 14.4 mm were released into the wild, and attributed this high survivorship to the physical and biological conditions present at the release site. Tegner and Butler (1985) reported no difference in survivorship, after 1 year, for two red abalone size groups that averaged 45 and 71 mm when seeded. We found more 20 mm than 10 mm live abalone after four weeks at liberty at both sites. However, due to the difficulties of locating small sized abalone, and the length of the field trial no conclusions can be made.

A high percentage of "unaccounted for" abalone has plagued the interpretation of results of most seeding projects in California, including this one. Although we observed a significant difference in survivorship according to seeding method, over 90% of the seeded abalone, overall, were not relocated. Abalone <5 cm long are difficult to locate because of the cryptic refuges they inhabit during daylight hours. It follows that fewer small size abalone are apt to be observed where optimum habitat exists. Yet, abalone are known to move extensively at night. Momma and Sato (1969) found that *H. discus hannai* moved 56.2 m during one night of foraging. The foregoing suggests that another method may be needed to assess the short-term as well as long-term results of abalone seeding projects.

One method that may be useful for estimating abalone seed survivorship is based on empty seed shell recoveries. Empty shells are easily seen because their nacreous interior is reflective and often exposed. Small empty abalone shells are not subject to extensive transport by prevailing currents and the majority of the shells are usually recovered (T. Ebert unpubl. data, Hines and Pearse 1982, Schmitt and Connell 1982). Shells could be transported by predators (e.g. *S. marmoratus* and *Octopus* spp.) or destroyed by crustaceans (e.g. *L. crispatus*). Using this criterion (no. empty abalone shells found=known mortality), our seed survivorship, after 4 weeks, was 98.4% and 89.0% at the seeding module and control sites, respectively. This survivorship seems inordinately high.

Efforts to enhance California's abalone populations, either by transplanting mature adult stock, or by seeding smaller size, hatchery-reared abalone, have spanned a 30 year period. But, the results of either method has been difficult to assess. The transplant method generally employs a relatively small number of large abalone which are ready to spawn and presumably do so. The success of the transplant may not be dependent upon long-term adult survivorship, but survivorship of their offspring. Adult transplants are conducted at the "expense" of one region of the fishery to enhance another. This practice may not be prudent given that the fishery is being fully exploited. Field studies (Giorgi and DeMartini 1977), and laboratory studies (Ebert and Houk 1984) show that the onset of sexual maturity in the red abalone occurs at about a 4 cm shell length. These smaller size red abalone exhibit greater sexual vigor in the laboratory, when compared to larger adults ($\geq$15 cm), and may spawn thrice annually (Ebert and Houk 1984). Presumably this sexual vigor occurs in nature and may serve to enhance recruitment through broadcasting gametes during most or all annual oceanographic regimes. Laboratory and field observations made over several years indicate that hatchery-reared abalone respond similarly to natural population abalone with respect to predator-prey relationships. For these reasons we suggest that small hatchery-reared abalones be seeded in future programs rather than the transplantation of larger abaione. The red, green, and pink abalone species are routinely cultivated, and available.

CONCLUSIONS

The results of this study indicate that the use of an abalone collector-transporter, seeding module method offers:

(i) An efficient method to collect, transport, and seed relatively large numbers of abalone;
(ii) Reduced handling stress on abalone;
(iii) An acclimation period for abalone free from potential predators;
(iv) A timed-release mechanism that permits abalone dispersal from the seeding module at an optimum time.

Further research is needed on optimizing abalone seed size and survivorship, and the development of a reliable method to assess the results of a seeding program.

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THE SURVIVAL AND GROWTH OF TRANSPLANTED ADULT PINK ABALONE, *HALIOTIS CORRUGATA,* AT SANTA CATALINA ISLAND[1]

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Pink abalone, *Haliotis corrugata,* populations, once abundant at Santa Catalina Island, have declined drastically. During January and April 1983, 517 adult pink abalone were experimentally transplanted from San Clemente Island to Emerald Bay on the northeast side of Santa Catalina Island as a potential concentrated spawning stock.

By February 1984, the shells of 91 (18%) dead abalone had been recovered, and only 24 (5%) live abalone could be located at the transplant site. The loss of the remaining 402 (78%) tagged abalone is believed due to illegal take. Changes in length of 12 of the live abalone ranged from −8 to +7 mm ($\bar{x}$ = 0 mm), with only three showing growth. Growth was affected by the disappearance of the local kelp, due to an influx of warm water associated with an El Nino event.

INTRODUCTION

The pink abalone, *Haliotis corrugata,* is a valuable commercial and recreational species in southern California. Once abundant on the mainland south of Pt. Conception and around some of the Channel Islands, their numbers have greatly declined. California commercial landings of pink abalone peaked at 1,507,593.6 kg (in the shell) in 1952, and fell to 25,812.6 kg by 1984 (California Department of Fish and Game landing receipts). Commercial passenger fishing vessel (CPFV) records show a high of 16,292 abalone taken at Santa Catalina Island in 1973 and only 2,296 in 1983, the bulk of the harvest being pink and green abalones.

In 1975 the California Department of Fish and Game (CDFG) identified six major causes for the decline in abalone populations. The causes were sea otter range expansion, mortality of sublegal sizes, over harvesting, competition from sea urchins, illegal harvesting, and loss of habitat (Burge et al. 1975). Encouraged by Japanese reports of successful abalone enhancement, one of the recommendations made by CDFG was to embark on an experimental abalone enhancement program. Ocean outplant of hatchery raised juvenile abalone and transplantation of native adult spawning stocks were two methods selected by the CDFG and Scripps Institution of Oceanography for further study and evaluation.

Successful transplants of adult green abalone, *H. fulgens,* have been made by CDFG and Scripps biologists in recent years (Tegner in press). Also two transplants of adult pink abalone were made at Laguna Beach; 375 were planted there in 1975 and 109 in 1976. After one year, good survival and growth were observed. No inter-island transplanting was undertaken.

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In 1982 we selected an area of good abalone habitat, which supported few native (pink and green) abalone, within an area closed to the take of invertebrates on the northeast side of Santa Catalina Island. Early in 1983 two groups of tagged and measured adult pink abalone were transplanted from San Clemente Island to Santa Catalina Island. Here we report on the survival and growth of these transplants.

STUDY AREA

Santa Catalina Island is approximately 37 km offshore of the southern California mainland. The northeast side of the island between Lion Head Pt. and Arrow Pt. is closed to the take of invertebrates between the high tide mark and 304.8 m (1000 ft) seaward beyond the low tide mark. The transplant site (lat 33° 28'N, long 118° 31.5'W) consists of 2024 m^2 of rocky bottom, 3–12 m deep, west of Indian Rock. The substrate is good pink abalone habitat with rocky outcrops, boulders, low lying vertical relief and sediment/rock interfaces. The Indian Rock area is surrounded by sandy substrate, which restricts abalone movement (Cox 1962), and is located inside Emerald Bay at the western end of the closure area (Figure 1). Emerald Bay is a popular anchorage for recreational boaters and CPFV dive boats. A bed of giant kelp, *Macrocystis pyrifera,* with a red algal understory was present at the start of the study.

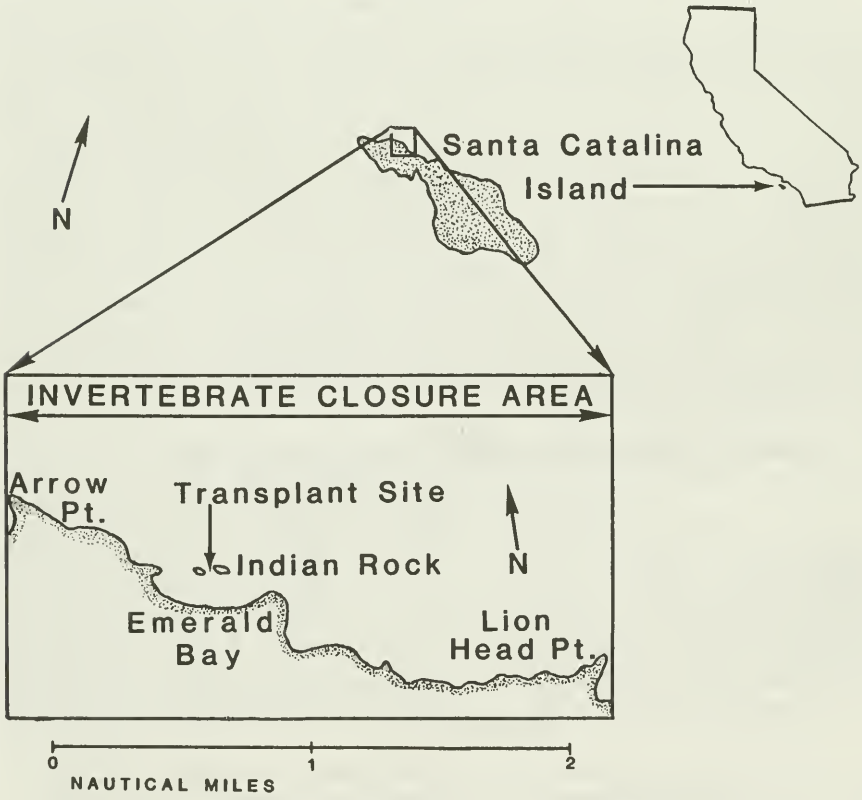

FIGURE 1. Transplant site at Indian Rock, Santa Catalina Island.

MATERIALS AND METHODS

Adult pink abalone were collected from various locations at San Clemente Island. The abalone were tagged, measured, and then placed on a thick net lining the flooded stern well of the R/V KELP BASS. The tags, imprinted stainless steel washers strung on stainless steel wire, were threaded through the two most anterior, complete respiratory pores of each abalone. Length and width of each animal were measured to the nearest mm with vernier calipers, and any injuries were noted. The net prevented the abalone from firmly attaching to the smooth deck, thereby reducing the chance of injury when the abalone were removed for replanting. Seawater was continuously pumped in at the rate of 38 litre/s. At Santa Catalina Island, each individual abalone was replanted on a rocky surface suitable for attachment, and observed briefly to ensure attachment to the substrate.

We returned several times to the transplant area and collected tagged shells to attempt to quantify mortality. A one-year post plant survey to determine survival and growth of the transplanted animals was carried out. The transplant site was thoroughly searched for one hour, and all tagged abalone encountered were measured, unless their removal would have resulted in fatal injury.

RESULTS

Five-hundred seventeen adult pink abalone, which averaged 141 mm (range 95 to 183 mm), were transplanted in two groups in early 1983 (Table 1). Cuts and abrasions received during collection were greater (29% vs. 14%) in the January group, as was the observed total mortality (27% vs. 10%). The transplanted abalone were in good condition when checked in April, July, and December 1983, and were noted to be feeding and responding normally, although their numbers appeared to be decreasing. During the study 91 tagged abalone shells were recovered by CDFG personnel and the public. After an intensive search in February 1984, we found 24 tagged abalone, 12 of which were measured underwater and replaced. The other 12 abalone were not measured because of the risk of injury. The measured animals ranged in size from 117 to 149 mm. Growth (change in shell length) ranged from minus 8 to 7 mm ($\bar{x} = 0$ mm; SD $= \pm 4$ mm), with only three abalone showing an increase in length. The remaining 402 abalone (78% of the transplant) were not located as live animals or shells.

TABLE 1. Transplant of Adult Pink Abalone at Santa Catalina Island, California, 1983.

	Transplant Date			
	January 10–14	*April 4–8*	*Total*	*Percent*
Abalone Planted Initially	237	280	517	
Transplant Injuries	69	40	109	21.1
Observed Mortality	64	27	91	17.6
One-Year Post Plant Survey				
Live Abalone			24	4.6
Abalone Unaccounted For			402	77.8

DISCUSSION

The one-year post transplant survey documented an unexpectedly low number of 24 surviving abalone. The disappearance of 78% of the animals

cannot be attributed to injury, predation, starvation, migration, or other natural factors. Green abalone have been successfully established on the mainland under similar conditions by CDFG/Scripps transplants (Tegner in press), and the CDFG transplant of pink abalone to Laguna Beach was considered successful based on a 34% recovery rate after one year. Hence a pink abalone transplant to Santa Catalina Island was considered viable. A large portion of the transplanted pink abalone were expected to successfully adapt to their historic habitat.

Despite special care, abalone are sometimes cut or abraded during collection. These injuries, or stress induced by handling, will often attract predators or scavengers and result in the death of the abalone (Tegner and Butler 1985). Based on previous tagging studies, initial mortalities of 10 to 20% were expected. Since pink abalone are more susceptible to picking and replacement injury (Burge et al. 1975) than other California species, initial mortality exceeding 20% was not considered unlikely. In the January collection, from the northeast side of San Clemente Island, it was found that the pink abalone's foot often blistered where the abalone iron contacted it and that cuts were frequent. In addition, many of these animals appeared stunted and lethargic. The pink abalone collected in April from the northwest side of the island appeared to be healthy but were still easily cut. The higher injury rate (29% vs. 14%) and mortality (27% vs. 10%) of the January group was probably a result of the general condition of the animals (Table 1).

A low level of natural mortality was expected for the relatively large abalone used in this study. Doi et al (1977) calculated a natural mortality (M) estimate of .35 for pink abalone. Although not all shells are recovered, losses due to natural mortality result in empty shells.

Another possible source of shell loss might be movement of live abalone away from the site. Migration of pink abalone is not common. After following the movement of pink abalone at Santa Catalina for several years Tutschulte (1976) concluded "that adult pink abalone do not migrate once they take up residence on the open substrate". At Indian Rock there was no evidence of abalone movement. The expanse of sand surrounding the site may also have impeded abalone movement away from the site. During post-planting visits to the site we noticed little movement of the tagged abalones, and we frequently found animals in the same location from one visit to the next. Also contiguous rocky areas and a reef 15 m from site were searched, as was the sand surrounding the site. No live abalone or shells were found. If these abalone had migrated we should have noticed major movement within the site and should have found animals or shells in the surrounding areas.

Starvation was probably not the reason for the disappearance of the tagged abalone, although food supplies were reduced. MacGinitie and MacGinitie (1966) reported that starvation did not stimulate pink abalone to move in an area off Laguna Beach denuded of seaweed. Abalone can survive for extended periods without food. Tegner and Levin (1982) ran food deprivation experiments on red abalone, and found the LD50 was 203 days with a tendency for the smaller animals to die first. However, the shells of those abalone that did starve would remain.

Illegal take is the most likely cause of the disappearance of transplanted abalone from this site. Emerald Bay is a popular recreational dive site with 101 rented moorings. In one case a recreational diver reported harvesting three of the transplanted abalone while assuming the site was not within the closure. The Lion Head to Arrow Point invertebrate closure does not appear to be well known or regularly enforced. No specific printed matter is available on the closure and no signs are posted on the beach.

Burge et al. (1975) reported average annual growth for pink abalone at San Clemente and Santa Cruz Islands of 10 mm for animals in the 136 to 145 mm size range. The poor growth of the surviving Catalina transplants could reflect measurement error, but more likely was the result of the poor conditions at Emerald Bay. The El Niño event that began in late 1982 caused deepened isotherms at Santa Catalina Island resulting in nutrient limited water. The island's algal community was devastated by the warmer than usual water (Zimmerman and Robertson 1985). Giant kelp, an important food item for abalone, disappeared from the transplant site, as did most of the algal understory. Food scarcity severely impacts abalone growth (Cox 1962) but the low survival of these pink abalone is considered an anomaly. This study strongly suggests that a fishing closure area does not always protect an experimental site. Future abalone transplant sites should be selected with the added criteria of minimal diving and boating activity.

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RECORDS OF THE DEEP-SEA SKATES, *RAJA (AMBLYRAJA) BADIA* GARMAN, 1899 and *BATHYRAJA ABYSSICOLA* (GILBERT, 1896) IN THE EASTERN NORTH PACIFIC, WITH A NEW KEY TO CALIFORNIA SKATES [1]

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The broad skate, *Raja (Amblyraja) badia,* previously described in the eastern Pacific from the holotype is here recorded from off central Panama north to Vancouver Island, British Columbia and redescribed from two recently collected California specimens. External morphological characters, counts, and measurements of these specimens are provided. The deepsea skate, *Bathyraja abyssicola,* previously described from two adult males, is here recorded from 22 specimens ranging from West Cortes Basin, California, to the Pacific coast of central Japan. External morphological characters, counts, and measurements are given from nine specimens, including juveniles and adults of both sexes, from off southern and central California. An updated key for field identification of adults and subadults of the nine species of skates currently known from California waters is provided.

INTRODUCTION

Due to their relatively large size and the great expense associated with collecting and preserving specimens, chondrichthyan fishes are often rather poorly represented in museum collections, especially deep-water species. Published descriptions and identification keys based on the relative paucity of such specimens, not to mention our knowledge of their biology and distribution, are too often fragmentary and incomplete. We found this to be the case with the skates *Raja badia* and *Bathyraja abyssicola.*

Garman (1899) described *Raja badia* from a single juvenile female, MCZ 1008-S, collected off the Pacific coast of Panama. The only subsequent published descriptions of *R. badia* (Garman 1913, Beebe and Tee-Van 1941) are based on this account.

Three additional eastern Pacific records of *R. badia* have been reported, but with little further comment. Taylor (1972) briefly recorded the capture of a second specimen from the Gulf of California. Yves et al. (1981) first listed the species from Canadian waters (off Vancouver Island). They also applied the vernacular "broad skate" to the species. Eschmeyer et al. (1983) briefly described a hardnosed skate (as *Raja* sp.) from off British Columbia and Oregon, noting it was "Most likely the adult of *Raja badia* . . . ." While Yves et al. (1981) and Eschmeyer et al. (1983) did not identify individual specimens, the Canadian record was based on BCPM 979-11101. The Oregon record was based on a 950 mm total length (TL) adult male collected off Oregon in 1968

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(L. J. V. Compagno, J. L. B. Smith Institute of Ichthyology, pers. comm.). We have been unable to locate this Oregon specimen, and have little additional data on it. A fifth eastern Pacific specimen, also from off Oregon (OS 5035), is known, but it is currently being studied by M. Stehmann (Institut für Seefischerei, Hamburg, Fed. Rep. of Germany).

Although Ishihara and Ishiyama (1986) gave an "Oregonian" distribution for *Raja badia,* this species has not been recorded previously from off California. As a result of collections made by research vessel DAVID STARR JORDAN for the National Marine Fisheries Service, two juveniles of *R. badia* are now known from California waters, a male (CAS 58604) captured in 1381-1404 m off Pt. Sur and a female (SIO 87-77) captured in 1280 m off Half Moon Bay.

Gilbert (1896) described *Bathyraja abyssicola* (as *Raja*) from an adult male (USNM 48623) taken off the Queen Charlotte Islands, British Columbia. This specimen was collected in 2903 m, about which Gilbert commented ". . . the greatest depth recorded for any species of skate . . ." a record which continues to stand after more than ninety years. Subsequent published descriptions of *B. abyssicola* (Jordan and Evermann 1898, Garman 1913, Clemens and Wilby 1949, Hart 1973) are based on this account.

Grinols (1965) recorded *B. abyssicola* from off northern Oregon in 1463-1554 m. He noted that this "rare species is known from only 4 recorded specimens . . ." [USNM 48623 (holotype), UW 19372 (now missing, T. Pietsch, University of Washington, pers. comm.), UW 19393, and USNM 73913]. Miller and Lea (1972) reported an additional specimen (SIO 62-692) from off North Coronado Island. This extended the known range to southern California.

Bathyraja abyssicola has been reported recently from the western North Pacific. Dolganov (1983) gave a brief description, counts, and measurements of six specimens collected by Soviet vessels between Japan and the Bering Sea, however he incorrectly referred to the authorship of the species as "Gilbert and Thoburn, 1895." Nakaya (1983) and Masuda et al. (1984) published photographs and short descriptions of an adult male (HUMZ 78181) collected in 1110 m off the Pacific coast of northern Japan. Ishihara and Ishiyama (1985) redescribed the species from a re-examination of data and drawings of the holotype made previously (H. Ishihara, Institute of Skatology, Fujisawa, Japan, pers. comm.), plus the western Pacific specimen. They provided a table of counts and measurements for both specimens and a description of the neurocranium and adult male clasper of HUMZ 78181, important structures in skate systematics. Ishihara and Ishiyama (1986) figured the scapulocoracoid from a second western Pacific specimen of *B. abyssicola* (MTUF 25270), collected off central Honshu Island in 800–1000 m. (H. Ishihara, pers. comm.). Tanaka (1987) published a photograph of a skate which greatly resembles *B. abyssicola* taken by the submersible SHINKAI 2000 in Suruga Bay, Japan at 1350 m.

Thus, *B. abyssicola* is known in the literature from only five specimens from the eastern Pacific and eight from the western Pacific. It has been adequately described, however, from only two large adult males. Descriptions of juveniles and adult female *B. abyssicola* are lacking. Additionally, disagreement in recent literature as to the number of median nuchal thorns as a key character for field identification (Wilimovsky 1958, Miller and Lea 1972, Ishihara and Ishiyama,

1985), as well as other discrepancies, especially in the earlier literature, are attributed to an inadequate sample size.

We provide additional data on the external morphology, counts and measurements, and report new records and range extensions of both *R. badia* and *B. abyssicola*. In addition, we correct some errors noted in our literature review. Finally, we present an updated key for field identification of adults and subadults of the nine species of skates known from California waters.

METHODS AND MATERIALS

Preserved specimens examined for this study were measured to the nearest millimeter (mm). Internal counts were made from radiographs. Counts and measurements were generally made according to the methods proposed by Hubbs and Ishiyama (1968) and Ishiyama and Ishihara (1977), with the following exceptions: (i) orbit length was externally measured and included the orbital cavity and overlying tissue, thus differing slightly from that made on cleaned and dissected preparations; (ii) interbranchial distance to first gill slit (g. s. #1) was measured between the inner margins of the left and right first gill slits and differs somewhat from the measurement "over 1st gill slits" of authors; (iii) we record both distal and proximal clasper lengths, but use proximal clasper lengths, but use proximal clasper length as the standard for these measurements. Total length (TL) is the basis for all body proportions unless otherwise indicated. Terminology for thorn patterning follows Stehmann and Bürkel (1984).

Owing to their relative scarcity in museum collections, specimens were not dissected to make cranial or skeletal preparations, determine gut contents, condition of gonads or clasper structures, or to count spiral valve turns. We did, however, partially dissect the dorsal portion of the left scapulocoracoid of a somewhat mutilated *B. abyssicola* (SIO 71-201) for comparison with that of a western Pacific specimen (MTUF 25270). We also radiographed and dissected the left clasper of SIO 85-68 for comparison with drawings of that of the western Pacific specimen (HUMZ 78181) published by Ishihara and Ishiyama (1985). Institutional abbreviations are as listed in Leviton et al. (1985).

Material Examined

Raja badia

CAS 58604 (568 mm ♂); SIO 87-77 (601 mm ♀).

Bathyraja abyssicola

CAS 38013 (2; 1191 mm ♂, 1316 mm ♀); CAS 38289 (672 mm ♀); CAS 58481 (3; 622 mm ♀, 676 mm ♂, 684 mm ♂); MTUF 125270 (1294 mm ♀; left scapulocoracoid only); SIO 71-201 (ca. 1010 mm ♀); SIO 85-45 (1233 mm ♀); SIO 85-68 (1315 mm ♂); USNM 73913 (735 mm ♀; radiograph).

Raja (Amblyraja) badia Garman, 1899

(Figure 1)

Diagnosis

A medium sized *Raja* (to 985 mm TL); disc rhomboid, width 1.3 times in disc length; dorsal surface of disc and tail covered with prickles; rostrum with greatly

enlarged thornlets in random pattern; one pair each of preorbital, postorbital and interspiracular thorns; two or three pairs of scapular thorns; continuous row of 24–29 thorns along midline of body and tail; tail short, with row of enlarged thornlets on either side of median thorns (more pronounced anteriorly); ventral surface completely smooth.

FIGURE 1. *Raja (Amblyraja) badia* Garman. Left, dorsal view of CAS 58604, photo by B. S. Eddy, Right, snout region of same specimen, photo by G. D. Zorzi.

Description

A full redescription of this species will be given by Stehmann, Ishihara and Nakaya (in prep.). We include the following description of the California specimens (CAS 58604; SIO 87-77) to distinguish the species for the aid of fisheries workers who may encounter this skate in the future. Proportional measurements, expressed as percent TL, are given in Table 1.

TABLE 1. Proportional Measurements (mm) And Counts Of *Raja (Amblyraja) badia*.

	CAS 58604		*SIO 87-77*	
	mm	*% TL*	*mm*	*% TL*
Total length	568	–	601	–
Disc width	431	75.9	443	73.7
Head length	138	24.3	141	23.5
Disc length	322	56.7	337	56.1
Disc depth between orbits	28	5.0	29	4.8
Greatest disc depth	42	7.4	43	7.1
Trunk length	202	35.6	202	33.6
Tail length	228	40.1	258	42.9
Tail width, end P2	23	4.0	18	3.0
Tail depth, end P2	19	3.3	20	3.3
Preorbital length	83	14.6	88	14.6
Prespiracular length	112	19.7	118	19.6
Snout tip to maximum disc width	225	39.6	235	39.1
Predorsal 1 length	497	87.5	522	86.9
Predorsal 2 length	519	91.4	550	91.5
Snout tip to caudal fin origin	540	95.1	580	96.5
D1 origin to tail tip	71	12.5	80	13.3
Prenarial length	74	13.0	74	12.3

TABLE 1. Proportional Measurements (mm) And Counts Of *Raja (Amblyraja) badia*.—Continued

	CAS 58604		*SIO 87-77*	
	mm	*% TL*	*mm*	*% TL*
Preoral length	98	17.3	100	16.6
Prebranchial length	146	25.7	138	23.0
Snout tip to gill slit #5	195	34.3	180	30.0
Snout tip to vent center	325	57.2	324	53.9
Precaudal body length	340	59.9	343	57.1
Corneal length	12	2.1	14	2.3
Orbit length	28	4.9	27	4.5
Interorbital distance	37	6.5	36	6.0
Spiracle length	15	2.6	19	3.2
Interspiracular distance	55	9.7	56	9.3
D1 base length	24	4.2	26	4.3
D1 vertical height	9	1.6	12	2.0
D2 base length	22	3.9	29	4.8
D2 vertical height	11	1.9	11	1.8
Interdorsal distance	3	0.5	0	0.0
D2 to caudal fin origin	0	0.0	0	0.0
Caudal base length	24	4.2	25	4.2
Caudal upper lobe vertical height	3	0.5	3	0.5
Lateral fold length (avg)	198	34.9	224	37.3
Nasal curtain length	33	5.8	30	5.0
Nasal curtain width	12	2.1	16	2.7
Internarial distance	77	13.6	65	10.8
Mouth width	75	13.2	78	13.0
Interbranchial distance, g. s. #1	121	21.3	125	20.8
Interbranchial distance, g. s. #5	78	13.7	90	14.8
Pelvic fin anterior lobe length	71	12.5	67	11.1
Pelvic fin posterior lobe length	80	14.1	79	13.1
Clasper length, distal	21	3.7	–	–
Clasper length, proximal	34	6.0	–	–
Counts				
Tooth rows in upper jaw	42		37	
Pseudobranchial folds (r/l)	10/11		11/11	
Vertebrae, trunk	33		33	
Vertebrae, predorsal-caudal	52		57	
Pectoral fin radials	65		65	
Pelvic fin radials	19		20	
Preorbital thorns	1 pr		1 pr	
Postorbital thorns	1 pr		1 pr	
Interspiracular thorns	1 pr		1 pr	
Scapular thorns	3 pr		2 pr	
Total median thorns	25		22	

Disc rhomboid, 1.3 times as broad as long. Tip of snout moderately produced, broadly rounded. Anterior margins of disc form almost a right angle; margins gently convex from behind tip of snout to approximately the level of orbits, becoming weakly concave, then broadly rounded distally. Apex of disc sharply rounded at posterior margin. Posterior margin forming angle of about 105° with anterior margin; posterior margin moderately concave near apex, becoming

very gently convex at posterior tip, then broadly rounded to axil. Disc relatively thin. Depth between orbits less than 7% disc width; less than 10% at greatest disc depth (across scapula).

Head large, length nearly 25% TL. Eyes small, corneal length less than 50% interorbital distance. Spiracles slightly longer than cornea, with 10–11 prominent pseudobranchial folds. Nasal curtain lobular, with weakly developed fimbriae. Mouth moderately wide, nearly 20% disc width. Teeth homodont, retrorse, in 37–42 rows in upper jaw, mushroomlike, appearing as thin, ovoid crowns supported on short, sturdy, somewhat conical bases. Single, stout, sharp cusp arising from rear-center of each crown and projecting obliquely backward; cusp reinforced anteriorly by thin, median ridge running nearly all crown length, and posteriorly by heavy retrorse keel. Posterior teeth inclined backwards into oral cavity.

Five pairs of gill slits, nearly uniform in length except fifth pair of SIO 87-77, which is considerably shorter than anteriormost pairs.

Pelvic fins lobate, narrow, moderately long. Anterior margin of anterior lobe moderately to sharply rounded at tip. Posterior lobe broadly rounded, becoming sharply rounded at posterior tip; inner margin weakly concave to axil. Claspers of CAS 58604 (immature) stubby, uncalcified, with broadly rounded tips.

Tail relatively short, less than 43% TL, narrow, tapering gradually to tip. Tail with paired, continuous lateral folds, about equal in length, originating as ridges near base of tail, widen distally to folds along ventrolateral surface and terminate near tail tip. Two small dorsal fins, nearly equal, closely set. Female with no discernible interdorsal space, male with space of 3 mm. Dorsal fin base approximately twice as long as vertical height. Anterodorsal margins of both dorsal fins hyperboloid, terminating as sharply pointed tips; posterior margins sharply recurved, except second dorsal of female, which has a broadly rounded posterior margin. Caudal fin small, low, its height about 1% of tail length, formed as narrow, dorsal ridge immediately posterior to second dorsal fin, rising gradually from about 33% its base length to broadly rounded posterior margin. Ventral tip of tail with short, low, longitudinal keel.

Dorsal surface of disc and tail completely covered with prickles, skin especially rough in middorsal area posterior to spiracles. Enlarged thornlets in malar and alar areas in both specimens (representing both sexes). Rostral area covered with enlarged thornlets, many of which are greatly enlarged and appear as small thorns (Figure 1) in random pattern about rostral midline, not in distinct series; five to six principal thornlets with three to four smaller thornlets. One pair each of preorbital, postorbital and interspiracular thorns, two or three pairs of scapular thorns. Twenty-four to 29 thorns in continuous row along body and tail midline. No interdorsal thorns. Tail with row of enlarged thornlets on either side of median thorns, more prominent anteriorly. Pelvic fins smooth, except for prickles near posterior tip of posterior lobe. Ventral surface of disc and tail completely smooth.

Color of dorsal surface of male medium gray-brown, with numerous darker spots and blotches, especially toward apices of disc and along tail. Whitish beneath eyes. A conspicuous brown bar across scapular region. Snout, margins of disc and tip of pelvic fin anterior lobe dark. Dorsal surface of female dark

chocolate brown; dark spots and blotches present, but less discernible than those of male. Ventral surface of disc same color as dorsal surface, but margins of disc, pelvic fin anterior lobe and ventral surface of tail darker than other areas. Whitish blotches on snout and upper abdomen, nares, nasal curtain, mouth, gill slits, and cloacal opening. Female with three moderately large white interbranchial blotches. Lateral folds of both specimens whitish.

Remarks

Our description of the California specimens of *Raja badia* agrees in nearly all respects with Garman's (1899) description of the holotype, with the following exceptions: (i) the enlarged rostral thornlets do not form ". . . a couple of series," but appear in a random pattern about the rostrum. Radiographs reveal the locations of the largest of these thornlets coincide closely with the underlying rostral cartilage; (ii) the holotype is considerably smaller than the California specimens; from Garman's plate it appears to have more prominent rostral thornlets; (iii) Garman did not report a dorsal pigment pattern, but merely noted the color to be "chocolate brown," this possibly due to fading after nine years in alcohol. Both California specimens have distinctly rounded dark spots and irregular blotches on the tail and a wide brown bar across the scapular region; (iv) Garman described the teeth as ". . . resembling a pair of small parallel discs united by a short narrow column . . ." that is the teeth appeared to him somewhat spool-shaped. We found, on close examination, however, that the teeth appear mushroom-shaped; they have only one crown ("disc") supported by a conical base which flares out where it attaches to the dermis.

Owing to its rarity, virtually nothing is known of the life history of this species. The large head, wide mouth, and retrorse teeth suggest this species is capable of feeding on relatively large, active prey. We did not examine gut contents of the California specimens, but vertebrae and other calcified material seen in radiographs of CAS 58604 suggest fish and possibly crustaceans as prey. Sexual maturity of males occurs at about 900 mm TL, possibly less.

Raja badia is known from six, possibly seven, specimens from the eastern Pacific (M. Stehmann, pers. comm.; Table 2). Nakaya (1983) published photographs and brief descriptions of two morphologically similar specimens (listed as *Raja* sp.) from off Japan. Ishihara and Ishyiyama (1986) noted these specimens fit the description of *R. hyperborea* from the North Atlantic and Arctic (Stehmann and Bürkel, 1984), but the taxonomic status of these specimens remains unresolved (M. Stehmann, pers. comm.).

Bathyraja abyssicola (Gilbert, 1896)
(Figure 2)

Diagnosis

A large *Bathyraja* (to 1350 mm TL); disc bell-shaped; moderately triangular anteriorly, broadly rounded posteriorly. Disc slightly broader than long; orbit length equal to interorbital distance; both surfaces of disc and tail covered with denticles; median nuchal thorns 1–5, separated from continuous row of 21–33 medial thorns on trunk and tail; orbital and scapular thorns absent.

TABLE 2. Known Specimens Of *Raja (Amblyraja) badia* From The Eastern Pacific.

Collection Number	*Date Collected*	*Size (mm TL)*	*Sex*	*Location*		*Depth (meters)*	*Method of Capture*	*Reference*
				Latitude	*Longitude*			
MCZ 1008-S	10 Mar 1891	257	F	7°05′30″ N	79°40′00″ W	2322	Large Beam Trawl	ALBATROSS Sta 3392; Holotype (Garman 1899)
——	15 Jan 1968	950	M	44°38′42″ N	125°11′48″ W	1600	22′ Otter Trawl	CAYUSE, OTB 224. Specimen not located (L. J. V. Compagno, pers. comm.)
SIO 70-249	15 Jun 1970	—	—	27°22′24″ N	111°20′30″ W	1830–1888	25′ Otter Trawl	Taylor 1972
OS 5035	4 Apr 1973	985	F	43°22′00″ N	125°09′54″ W	1600	Otter Trawl	Misidentified as *R. inornata* (M. Stehmann, pers. comm.)
BCPM 979-11101	17 May 1979	930	M	48°37′30″ N	126°57′00″ W	1920	Sablefish Trap	Yves et al. 1981
CAS 58604	8 Dec 1985	568	M	36°15′18″ N	122°22′54″ W	1381–1408	Otter Trawl	DAVID STARR JORDAN
SIO 87-77	24 Jan 1987	601	F	37°25′35″ N	123°14′57″ W	1280	Otter Trawl	DAVID STARR JORDAN

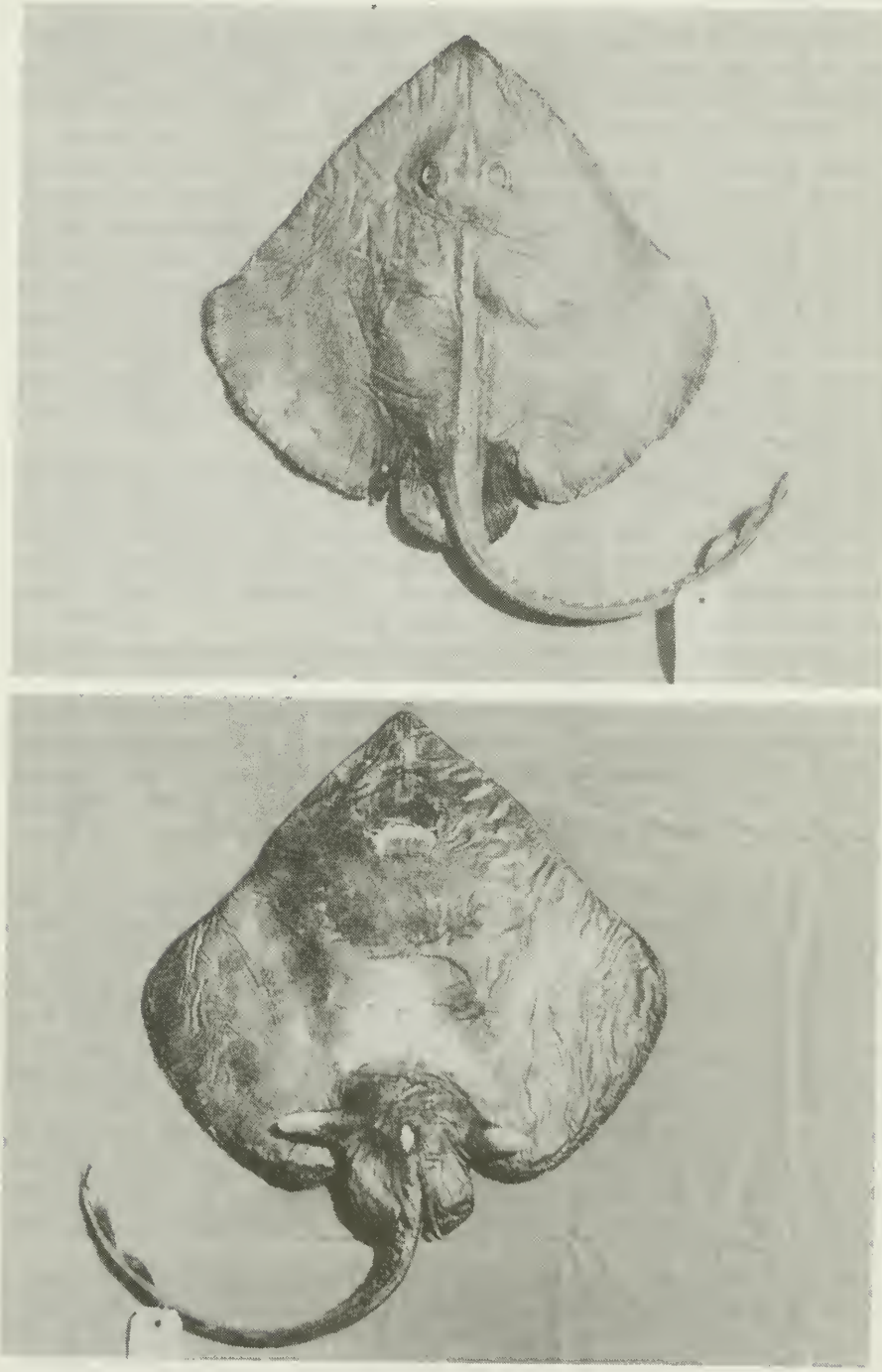

FIGURE 2. *Bathyraja abyssicola* (Gilbert). Upper, dorsal view of CAS 58481. Lower, ventral view of same specimen. Photos by M. E. Anderson.

Description

Adult males of *B. abyssicola* have been described in detail by Gilbert (1896) and Ishihara and Ishiyama (1985). We provide the following description of nine specimens of juveniles and adults of both sexes from off California. Proportional measurements, as percent TL, are given in Table 3.

Disc somewhat bell-shaped; moderately triangular anteriorly, broadly rounded posteriorly, slightly broader than long. Greatest disc width in posterior half of disc, 55.9–65.5%disc length. No differences in disc shape between sexes or sizes. Tip of snout moderately produced, acutely rounded. Anterior margins of disc form less than right angle; gently convex from behind snout tip to about the level of orbits, becoming weakly to moderately concave, than broadly rounded to apex. Apices of disc broadly rounded. Posterior margins of disc form less than right angle; nearly straight to gently rounded, becoming sharply rounded at posterior tips, then weakly concave to axil. Disc moderately thin, more dorsoventrally depressed in juveniles than adults.

Head large, length nearly 25% TL. Eyes small, orbit length equal to interorbital distance, corneal length less than 50% interorbital distance. Spiracle slightly longer than cornea. Pseudobranchial folds 15–18, more prominent in larger individuals. Nasal curtain broadly rounded, with weakly developed fimbriae. Mouth weakly arched, somewhat narrow, 13.6–16.0% disc width. Teeth homodont, retrorse, in 31–36 rows in upper jaw.

Five pairs of gill slits; four anteriormost nearly equal, posteriormost markedly shorter.

Pelvic fins moderately elongate, broadly rounded. Anterior lobe with whitish tip. Posterior lobe broadly rounded to posteriormost tip; inner margin straight to axil. Claspers of both juvenile and adult males relatively long and thin. Claspers of SIO 85-68 mature, tips ovoid and bulbous. Left clasper 44.1% tail length; pseudosiphon 1 10% of proximal clasper length. No dermal denticles on dorsal surface.

Tail moderately long, narrow, stout anteriorly, tapering gradually to tip. Paired, narrow lateral folds present; asymmetric and discontinuous. Two relatively large dorsal fins, nearly equal, closely set, except in CAS 38013 (female), which has interdorsal distance nearly twice the mean. Interdorsal thorn present in most specimens. Anterodorsal margins of both dorsal fins hyperboloid, terminating in broadly rounded tips. Posterior margins straight to weakly rounded. Caudal fin small, low, completely separated from second dorsal fin (not formed anteriorly as narrow, distinct ridge, as noted for *R. badia*). Anterodorsal margin of caudal fin gently rounded, rising gradually to broadly rounded tip. Posterior margin broadly rounded, extending beyond tail tip. Ventrally developed caudal fold formed anteriorly as low, fleshy ridge, widening slightly posteriorly to broadly rounded tip connected to and extending slightly beyond tail tip.

Dorsal surface of disc and tail completely and evenly covered with denticles, except on distal margins of disc and around eyes. Adult males with alar hooks in 3–5 irregular rows; no malar hooks. Nuchal thorns 3–5, separated from 21–28 median thorns in continuous row along trunk and tail. Scapular thorns absent. Interdorsal thorn present in eight of nine specimens with intact tails. Single

specimen without interdorsal thorn, CAS 38013 (male), with extremely short interdorsal distance (0.3% TL). Tail with two bands of enlarged denticles on either side of median thorns.

Ventral surface of disc covered with minute denticles except for midsnout and abdominal region of juveniles. Ventral surface of tail smooth anteriorly, minute denticles in mid- or posterior regions.

Dorsal surface of pelvic fin anterior lobe smooth in all. Ventral surface smooth in juveniles, but with prickles proximally in adults. Posterior pelvic fin lobe covered with prickles in all except at posterior tip.

Dorsal pigmentation generally monotone, uniform; colors of preserved specimens ranging from light gray to dark gray-brown, with slightly darker distal margins. Color in life uniform dark chocolate brown. Occasional, small, round spots of darker pigment occurring randomly on disc. Tip of pelvic fin anterior lobe whitish.

Ventral surface of disc same color as dorsal or slightly darker; distal margins of disc and tail darker. Whitish around mouth, posterior edges of labial folds, tips of pelvic fin anterior lobes, and tips of claspers. Gill slit distal margins whitish; much darker posterior to gill openings. Whitish around cloacal opening, surrounded by darker ring. Lateral folds whitish. Males with large, irregular whitish blotches, often with numerous dark spots, on abdomen; whitish blotches greatly reduced or, more usually, absent in females.

Remarks

Our description of the California specimens of *B. abyssicola* agrees in nearly all respects with that of the holotype (Gilbert, 1896), with the following exceptions: (i) Gilbert stated, ". . . the greater part of the upper surface of ventrals . . . naked." We found only the dorsal surfaces of the anterior pelvic lobes and the posterior tips of the posterior lobes naked; (ii) Gilbert noted, "A wide lateral fold along either side of tail." We found the lateral fold width to range 1.0–2.8% its length, and, while qualitative modifiers are certainly subjective, we characterize the lateral folds as relatively narrow; (iii) Gilbert also noted the ". . . caudal fold but little higher than the lateral ones, with which it becomes confluent at tip of tail." We found the lateral folds terminate posteriorly in advance of the tail tip, whereas the caudal fin (fold) extends beyond the tail tip; (iv) neither Gilbert nor Ishihara and Ishiyama (1985) commented on the ventrally developed caudal fold, which was present in all specimens with intact tails we examined.

Gilbert (1896) did not state the total length of the holotype, which we calculated from his table of measurements to be 1,350 mm, or approximately 4.5 ft. Jordan and Evermann (1898) noted the length to be ". . . 45 inches long . . ." This mistake went unnoticed by Garman (1913), Grey (1956; as 1,143 mm), as well as Ishihara and Ishiyama (1985), who also listed it as 1,143 mm. Thus, proportions as percent TL given for the holotype by Ishihara and Ishiyama (1985; table 1) should be recalculated on the basis of 1,350 mm TL.

Counts for trunk vertebrae and predorsal-caudal vertebrae for USNM 73913 vary considerably from those made for the nine California specimens (Table 3). Some variation also exists between these specimens and western Pacific *B. abyssicola*. HUMZ 78181 differs by having only one nuchal thorn, 31 median

TABLE 3. Proportional Measurements (mm) and Counts of *Bathyraja abyssicola*.

	CAS 38013-1	*CAS 38013-2*	*CAS 38289*	*CAS 58481-1*	*CAS 58481-2*	*CAS 58481-3*	*SIO 71-201* *	*SIO 85-45*	*SIO 85-68* †	*USNM 73913* ‡	*Range (% of TL)*	*Mean*
Total length	1,191	1,316	672	622	676	684	1,010	1,233	1,315	735	–	–
Disc width	681	724	391	352	360	397	563	727	782		53.2–59.5	56.9
Head length	274	294	152	143	141	154	246	299	272		20.7–24.4	22.6
Disc length	652	644	349	321	338	358	556	683	698		48.9–55.4	52.5
Trunk length	355	384	186	162	188	188	296	362	395		26.0–30.0	28.5
Tail length	562	638	334	317	347	342	468	572	648		46.3–51.3	48.8
Preorbital length	204	197	101	94	92	98	161	201	174		13.2–17.1	15.1
Prespiracular length	221	227	123	115	114	118	200	249	222		16.9–20.2	18.2
Snout tip to maximum disc width	386	422	196	197	210	200	327	398	414		29.2–32.4	31.3
Predorsal 1 length	1,053	1,149	582	531	574	588	905	1,013	1,158		84.9–89.6	87.2
Predorsal 2 length	1,100	1,216	616	559	613	621	–	1,150	1,223		89.9–93.3	91.8
Snout tip to caudal fin origin	1,144	1,268	644	593	647	656	–	1,195	1,271		95.3–96.9	96.1
D1 origin to tail tip	138	167	90	91	102	96	105	140	157		10.4–15.1	12.8
Prenarial length	158	163	88	77	79	82	136	172	151		11.5–13.9	12.6
Preoral length	193	205	105	96	96	101	174	213	180		14.2–17.3	15.8
Prebranchial length	272	281	146	139	131	145	234	294	280		19.4–23.2	21.6
Snout tip to gill slit #5	350	362	193	176	177	192	305	381	365		26.2–30.9	28.6
Snout tip to vent center	595	650	326	291	305	329	513	624	628		54.1–50.8	48.6
Precaudal body length	629	678	338	305	329	342	542	661	667		48.7–53.7	51.1
Corneal length	21	21	14	14	13	13	12	22	20		1.2– 2.3	1.8
Orbit length	46	49	28	23	28	27	42	49	49		3.7– 4.2	3.9
Interorbital distance	44	51	27	24	28	28	42	49	54		3.7– 4.2	4.1
Spiracle length	28	30	18	17	15	20	25	29	38		2.2– 2.9	2.5
Interspiracular distance	69	80	44	41	43	40	58	77	80		5.7– 6.6	6.1
D1 base length	43	44	28	28	29	29	35	44	48		3.3– 4.5	3.9
D1 vertical height	26	34	15	13	14	16	27	26	35		2.1– 2.7	2.3
D2 base length	41	43	27	27	30	28	–	38	44		3.1– 4.4	3.7
D2 vertical height	28	28	15	15	15	15	–	28	41		2.1– 3.1	2.4
Interdorsal distance	4	22	6	3	8	7	–	12	14		0.3– 1.7	1.0
D2 to caudal fin origin	6	10	4	5	8	3	–	6	7		0.5– 1.3	0.7
Caudal base length	40	51	28	28	30	31	–	41	37		2.8– 4.5	3.9

TABLE 3. Proportional Measurements (mm) and Counts of *Bathyraja abyssicola*.—Continued

	CAS 38013-1	*CAS 38013-2*	*CAS 38289*	*CAS 58481-1*	*CAS 58481-2*	*CAS 58481-3*	*SIO 71-201* *	*SIO 85-45*	*SIO 85-68* †	*USNM 73913* ‡	*Range (% of TL)*	*Mean*
Caudal upper lobe vertical height	10	9	4	4	5	6	–	10	11		0.6– 0.9	0.7
Lateral fold length (avg)	228.5	297.5	291	192.5	140	139.5	–	296.5	355		19.2–43.3	26.0
Nasal curtain length	42	44	25	24	22	25	39	42	37		2.8– 3.9	3.5
Internarial distance	90	118	51	47	46	51	82	99	102		6.8– 9.0	7.8
Mouth width	97	101	53	51	50	55	86	103	125		7.4– 9.5	8.2
Interbranchial distance, g. s. #1	182	209	113	98	99	108	164	201	205		14.6–16.8	15.8
Interbranchial distance, g. s. #5	131	145	76	67	68	78	113	144	140		10.0–11.2	11.0
Pelvic fin anterior lobe length	89	111	57	55	54	61	81	92	98		7.5– 8.9	8.1
Pelvic fin posterior lobe length	115	126	60	61	70	68	113	121	158		8.9–12.0	10.1
Clasper length, distal	85	–	–	–	19	25	–	–	217		–	–
Clasper length, proximal	122	–	–	–	35	41	–	–	282		–	–
Counts											*Range*	*Mean*
Tooth rows in upper jaw	31	33	32	35	33	35	34	32	34	36	31–35	33.2
Pseudobranchial folds (r/l)	16/17	17/17	17/15	18/18	16/15	18/16	18/18	16/18	17/16	–	15–18	16.8
Vertebrae, trunk	35	32	33	32	35	35	34	32	34	39	32–35	33.6
Vertebrae, predorsal-caudal	72	72	70	72	70	72	70	77	71	64	70–77	71.8
Pectoral fin radials	–	–	84	85	87	85	–	–	–	85	84–87	85.3
Pelvic fin radials	–	–	20	22	19	23	–	22	21	23	19–23	21.2
Median nuchal thorns	3	4	5	5	4	4	5	4	5	–	3– 5	4.3
Median tail thorns	21	27	28	26	24	26	–	27	28	–	21–28	25.9
Interdorsal thorn (y/n)	n	y	y	y	y	y	–	y	y	y	–	–

* Specimen was partially mutilated. Tip of tail was broken just anterior of D1, and completely missing caudal to it. Total length (1,010 mm) was not actually measured, but taken from data sheet and identification tag. Right pectoral and pelvic fins were badly abraded, making measurement of disc width approximate.

† Cranium crushed. Total length (1,315 mm) was actual measurement and does not take into account those few mm of the extreme tip of tail, which were missing.

‡ Due to its generally poor condition, we were unable to examine the specimen. Internal counts were made from a radiograph kindly loaned to us by K. Bruwelheide, National Museum of Natural History, Smithsonian Institution. Counts are for reference only, and are not included in calculations of Range and Mean.

thorns, 42 trunk vertebrae, interorbital distance greater than orbit length, spiracles as large as orbits, 13–14 pseudobranchial folds, preoral snout length 12.9% TL, dermal denticles on the posterior third of the dorsal surface of the claspers, the caudal fin developed only dorsally, and a few other measurements that vary slightly from those we obtained (Ishihara and Ishiyama 1985, H. Ishihara, pers. comm.). Photographs of this specimen published by Nakaya (1983) show it to have a greater number of dark spots on the dorsal surface of the disc and no large irregular whitish blotch on the ventral surface, a feature found on all males we examined.

Nevertheless, on the basis of comparison of clasper structures between HUMZ 78181 and the holotype, Ishihara and Ishiyama (1985) concluded the western Pacific form was conspecific with the holotype from the eastern Pacific. Our comparison of the left clasper of SIO 85-68 with drawings of the same of HUMZ 78181 (Ishihara and Ishiyama 1985, fig. 4)supports this conclusion.

A second western Pacific specimen of *B. abyssicola*, MTUF 25270, differs from California specimens in having a higher median thorn count (33) and lower preoral length (12.4% TL) (H. Ishihara, pers. comm.). Our comparison of the scapulocoracoid of this specimen with a dorsally dissected scapulocoracoid of SIO 71–201, ca. 1,010 mm TL, revealed a similarity in their shapes, location of the condyles, and size, position, and location of the anteriormost dorsal openings. The posteriormost dorsal fenestrae differed both in size and number, however, a condition recognized for *Bathyraja* species by Ishihara (pers. comm.).

Little more is known of the life history of *B. abyssicola* than of *R. badia*. It also has been collected in great depths and appears eurybathic (362–2,903 m). Its large head and retrorse teeth suggest this species is also capable of feeding on relatively large, active prey, but we cannot corroborate this.

Juveniles are more dorsoventrally depressed than adults. The bases of both dorsal and caudal fins are comparatively longer in juveniles and the distance "D1 origin to tip of tail" is longer, indicating ontogenetic decrease in fin size. Juveniles lack denticles on the abdominal region of the disc and ventral surface of the pelvic fin anterior lobe.

Sexual maturity of males occurs at about 1,100 mm TL, however, we know of no specimens in the 750–1,000 mm range which would have enabled us to make a closer estimate. CAS 38013 (1,191 mm TL) did not have fully calcified claspers and lacked the alar hooks of mature males.

Bathyraja abyssicola is known from 16 specimens (Table 4), not including an additional six from the western Pacific reported by Dolganov (1983) from unspecified localities ranging between Japan and the Bering Sea. It ranges from west of Bishop Rock, West Cortes Basin, California (LACM 38378-1) to off the Queen Charlotte Islands, British Columbia, in the eastern North Pacific and from the Bering Sea to off Chosi, Pacific coast of Honshu Island, Japan (MTUF 25270), and possibly Suruga Bay (Tanaka, 1987). As a eurybathic, slope-dwelling species, its range appears to be continuous from at least California to Japan.

TABLE 4. Known Specimens of *Bathyraja abyssicola*.

Collection Number	*Date Collected*	*Size (mm TL)*	*Sex*	*Location*		*Depth (meters)*	*Method of Capture*	*Reference*
				Latitude	*Longitude*			
USNM 73913	31 Aug 1888	735	F	51°23′00″ N	130°34′00″ W	1,601	Large Beam Trawl	ALBATROSS Sta 2860; Miller and Lea 1972
USNM 48623	3 Sep 1890	1,350	M	52°39′30″ N	132°38′00″ W	2,903	Large Beam Trawl	ALBATROSS Sta 3342; Holotype Gilbert 1896; Ishihara and Ishiyama 1985
SIO 62-692	5 Dec 1962	1,160	M	32°25′12″ N	117°27′36″ W	1,280	Free Vehicle Set Line	AGASSIZ Cruise 6213, Sta 5, Set 4; Miller and Lea 1972
UW 19372	29 May 1964	—	—	—	—	1,462–1,554		? Grinols 1965; Specimen not located
UW 19393	29 May 1964	1,000 +	M	46°N	124° W	1,462–1,554		T. Pietsch, pers. comm.; ? Grinols 1965
SIO 71-201	1 Nov 1971	1,010	F	32°24′24″ N	117°29′30″ W	1,207–1,243	40′ Otter Trawl	AGASSIZ
CAS 38013-1	7 Aug 1976	1,191	M	36°29′24″ N	122°00′54″ W	362–369	92′ Otter Trawl	JOHN N. COBB
CAS 38013-2	7 Aug 1976	1,316	F	36°29′24″ N	122°00′54″ W	362–369	92′ Otter Trawl	JOHN N. COBB
CAS 38289	7 Sep 1976	672	F	35°06′12″ N	121°38′48″ W	1,259–1,277	Otter Trawl	DAVID STARR JORDAN
LACM 38378-1	22 Sep 1978	1,162	M	32°22′49″ N	119°24′46″ W	1,250–1,300	Sablefish Trap	
HUMZ 78181	22 Sep 1978	1,178	M	39°27′00″ N	142°33′00″ E	1,110		Ishihara and Ishiyama 1985
MTUF 25270	26 Jan 1985	1,294	F	35°40′00″ N	141°00′00″ E	800–1,000	Otter Trawl	Ishihara and Ishiyama 1986
SIO 85-45	6 Feb 1985	1,233	F	36°29′54″ N	122°18′18″ W	1,400	40′ Otter Trawl	CAYUSE
SIO 85-68	13 Mar 1985	1,315	M	36°25′12″ N	122°18′36″ W	1,407–1,414	40′ Otter Trawl	CAYUSE
CAS 58481-1	8 Dec 1985	622	F	36°15′18″ N	122°22′54″ W	1,381–1,408	Otter Trawl	DAVID STARR JORDAN
CAS 58481-2	8 Dec 1985	676	M	36°15′18″ N	122°22′54″ W	1,381–1,408	Otter Trawl	DAVID STARR JORDAN
CAS 58481-3	8 Dec 1985	684	M	36°15′18″ N	122°22′54″ W	1,381–1,408	Otter Trawl	DAVID STARR JORDAN

DISCUSSION

Nearly all known specimens of *R. badia* and *B. abyssicola* have been collected by fisheries research vessels using bottom trawls (Tables 2 & 4). At least one specimen of each, however, was collected in a commercial sablefish trap. Thus, fisheries biologists and commercial fishermen remain the most important sources for obtaining new specimens to learn more about the systematics and biology of these fishes, but most investigators are relatively unfamiliar with California's deep-sea fish fauna. After examining many specimens of each of California's skates, we have devised an updated key to the adults and subadults of the nine species presently known from California waters, the first since Miller and Lea's (1972) somewhat dated key.

Only two genera of skates occur in California waters, indeed, in the entire eastern North Pacific. The so-called "hardnosed" skates of the genus *Raja* Linnaeus are characterized by robust, stiff, rostral cartilages and, consequently, stiff snouts. The so-called "soft-nosed" skates of the genus *Bathyraja* Ishiyama are characterized by very slender, usually curved rostral cartilages and, consequently, pliable snouts. These characters can be reliably observed using radiography or by dissection of the snout. Another method, which works better with small specimens, is to hold the snout up to bright light. For several obvious reasons, these methods are generally impractical for field identification. A more common method is to simply bend the snout backward. The snout of *Bathyraja* species bends readily, that of *Raja* species only with sufficient effort and is usually very resistant to much bending. Even this method is not absolutely reliable, as snouts can be damaged by heavy gear.

Our key uses the presence or absence of orbital thorns as a convenient additional character for distinguishing the two genera. All *Raja* presently known from California waters have orbital thorns and all California *Bathyraja* do not. This key is not reliable for skates from outside California, as presence or absence of orbital thorns is not diagnostic for either genus. It will also be unreliable with very young individuals, as thorn characteristics are not well expressed in these. The following references should be consulted for additional information, illustrations, and terminology: Miller and Lea (1972), Hart (1973), Eschmeyer et al. (1983), and Stehmann and Bürkel (1984). Thorn terminology used in the key is illustrated in Fig. 3.

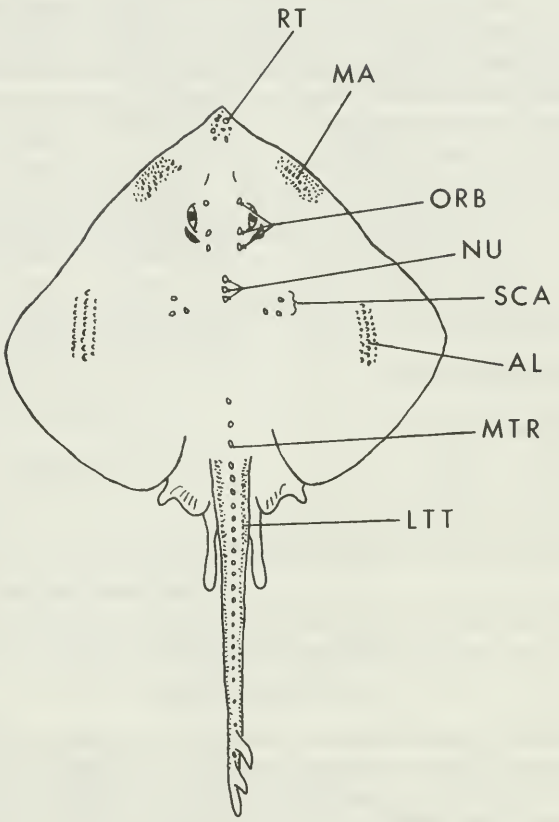

FIGURE 3. Composite sketch of dorsal surface of hypothetical skate showing thorn pattern for identification of California species. Abbreviations: AL, alar thorns (hooks); LTT, lateral tail thornlets; MA, malar thorns and thornlets; MTR, median thorn row; NU, nuchal thorns; ORB, orbital thorns; RT, rostral thornlets; SCA, scapular thorns.

Key to Adult and Subadult California Skates

1A. Snout stiff, not easily bent due to stout, broad, tapering rostral cartilage; orbital thorns present; anteriormost pectoral fin rays falling well short of rostral tip (genus *Raja* Linnaeus, 1758) 2

1B. Snout soft and pliable, rostral cartilage slender, orbital thorns absent; anteriormost pectoral fin rays extending almost to tip of snout (genus *Bathyraja* Ishiyama, 1958).....6

2A. Enlarged rostral thornlets present; two or three pairs of scapular spines present; ventral surface smooth.....*Raja badia* Garman, 1899

2B. Enlarged rostral thornlets and scapular spines absent 3

3A. Pelvic fins very shallowly notched; seismosensory pores on ventral surface of disc forming distinct right angle distal to gill slits; no lateral tail thornlets ..... *Raja binoculata* Girard, 1854

3B. Pelvic fins deeply notched; ventral seismosensory pores in random pattern or variously curved lines; lateral tail thornlets present or absent 4

4A. Lateral tail thornlets absent ..... *Raja rhina* Jordan and Gilbert, 1880

4B. Lateral tail thornlets present 5

5A. Anterior margin of disc nearly straight to slightly convex; median thorn row not extending anteriorly to vertical through pelvic fin origins ..... *Raja inornata* Jordan and Gilbert, 1881

5B. Anterior margin of disc nearly straight to deeply concave; median thorn row extending anterior to vertical through pelvic origins ..... *Raja stellulata* Jordan and Gilbert, 1880

6A. Scapular thorns present ..... *Bathyraja interrupta* (Gill and Townsend, 1897)

6B. Scapular thorns absent 7

7A. Nuchal thorns 1–5 ..... *Bathyraja abyssicola* (Gilbert, 1896)

7B. Nuchal thorns absent 8

8A. Ventral surface of disc smooth, except small patches of prickles on snout and near disc margin; dorsal surface of disc black ..... *Bathyraja trachura* (Gilbert, 1892)

8B. Ventral surface of disc covered with prickles; dorsal and ventral surfaces gray ..... *Bathyraja spinosissima* (Beebe and Tee-Van, 1941)

CONCLUSIONS

Raja (Amblyraja) badia Garman is added to the California ichthyofauna and new specimens of *Bathyraja abyssicola* (Gilbert) are reported and the species redescribed. This paper is a contribution to the knowledge of their morphology and distribution. Great individual variation is noted in these skates. The limits of this variability and, most importantly, determining if it is an expression of discrete populations, can only be learned by examining many more specimens. Our key to the California skates includes recently updated zoological nomenclature.

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DIFFERENCES IN YIELD, EMIGRATION-TIMING, SIZE, AND AGE STRUCTURE OF JUVENILE STEELHEAD FROM TWO SMALL WESTERN WASHINGTON STREAMS [1]

By

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From 1978 through 1984, we examined the yield, emigration-timing, size, and age structure of juvenile steelhead trout from two small, geographically distinct, Washington streams. Of the two study streams, one had an allopatric winter-run steelhead population (Snow Creek), and the other had a sympatric winter- and summer-run steelhead population (Gobar Creek). Annual smolt yields were greater in Snow Creek than in Gobar Creek. Mean seven year yields were 1,227 and 331, respectively. In contrast to Snow Creek, where the proportion of emigrant parr (age $\leq$ 1) averaged 20.1%, parr were a dominate proportion (86.1%) of the total number of emigrants from Gobar Creek. The mean date of outmigration was significantly different for smolts and parr between streams. Most steelhead smolts and parr emigrated from Gobar Creek in early May compared to mid-May in Snow Creek. Steelhead smolt and parr migrating from Snow Creek were larger than Gobar Creek juvenile steelhead migrants. The age structure of emigrating smolts from Gobar Creek averaged 15.8% age 1, 76.7% age 2, and 7.5% age 3. In Snow Creek, migrant smolts were comprised of 5.3% age 1, 86.3% age 2, and 8.4% age 3. The survival of emigrant parr to the smolt stage is likely related to the availability of suitable rearing areas in tributary and mainstem reaches. A river system approach to fishery management and habitat protection is discussed.

INTRODUCTION

In coastal streams and rivers of Washington State, juvenile anadromous steelhead trout, *Salmo gairdneri,* undergo a critical life history phase, migration to the ocean. Information about their downstream migration and age structure is important in understanding wild steelhead populations. Several researchers have reported the age structure of emigrating juvenile steelhead from rivers and streams in British Columbia, Canada (Maher and Larkin 1955, Narver 1969); Washington (Gudjonsson 1946, Larson and Ward 1954, Loch, Chilcote, and Leider 1985); Oregon (Wagner, Wallace, and Campbell 1968, Everest 1973); and California (Shapovalov and Taft 1954). Variations in size and age structure as they relate to emigration of juvenile rainbow trout have been reported by Stauffer (1972) and Kwain (1981) for some Great Lakes streams. In the Columbia River, juvenile salmonid downstream migration timing and age structure have been reported by Dawley et al. (1980), Dawley et al. (1981), and Loch (1982).

As part of a more comprehensive series of studies by the Washington Department of Wildlife, we monitored the downstream migration of juvenile salmonids from two geographically separated streams. One stream had an

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allopatric population of winter-run steelhead, and flowed directly into the ocean. The second stream had a sympatric population of winter-run and summer-run steelhead, and flowed into a major tributary of the Columbia River. Steelhead races are distinguished primarily by their relative sexual maturity at return and time of freshwater return from the ocean on their spawning migration (Withler 1966; Leider, Chilcote, and Loch 1986a). The purpose of this study was to compare downstream migration characteristics of juvenile steelhead from the two different locations and stream types. Specifically, we examined: (i) yield; (ii) emigration-timing; and (iii) size and age structure.

Because of the increasing environmental degradation of many stream habitat areas and the possible reduction of steelhead production, information on variation in juvenile freshwater life history characteristics associated with different types of rearing streams is important for the proper management of wild steelhead populations. Incorporation of this information into present habitat and harvest management plans may improve the survival rate of juvenile steelhead rearing in tributary and mainstem complexes, thereby improving production, and adult return rates.

STUDY AREA

Gobar Creek

Gobar Creek, a tributary of the Kalama River hence the Columbia River, is located in southwestern Washington (Figure 1). It is 9.6 kilometres (km) in length and has a natural barrier that prevents steelhead passage to the upper 1.6 km. The creek has a watershed area of approximately 55 km^2. Gobar Creek averages 8.0 metres (m) in width, has a moderate gradient (10 m/km), well developed riffle and pool sequences, and few pools deeper than 1.5 m. September flows average 0.50 m^3/s. Water temperature ranges from 5.4 to 9.7°C with a mean of 7.2°C (April–June). Habitat composition and substrate range from boulder-rubble-bedrock to cobble in the lower reaches (mouth to 1.6 km); gravel-cobble-rubble in the middle reaches (1.6 km to 5.3 km); and gravel-cobble to bedrock in the upper reaches (5.3 km to 9.6 km). Corresponding gradients for each longitudinal zone (lower, middle, and upper) are 12.5 m/km, 8.9 m/km, and 8.5 m/km, respectively. Dense deciduous vegetative cover is found along the banks. Over the course of our study, extensive logging has occurred throughout the watershed.

Fish species present include resident and anadromous cutthroat trout, *Salmo clarki;* winter- and summer-run steelhead trout (Leider et al. 1986a); coho salmon, *Oncorhynchus kisutch;* mountain whitefish, *Prosopium williamsoni;* Pacific lamprey, *Entosphenus tridentatus;* torrent sculpin, *Cottus rhotheus,* and coastrange sculpin, *C. aleuticus.*

Snow Creek

Snow Creek enters the head of Discovery Bay on the northeast side of the Olympic Peninsula (Figure 1). The creek has a watershed area of 52 km^2, and is 16.0 km in length with 10.4 km accessible to steelhead. Snow Creek has a mean stream width of 5.0 m with few pools deeper than 1.5 m. Stream gradient is 25 m/km overall and averages 12, 19, and 45 m/km in the lower, middle, and

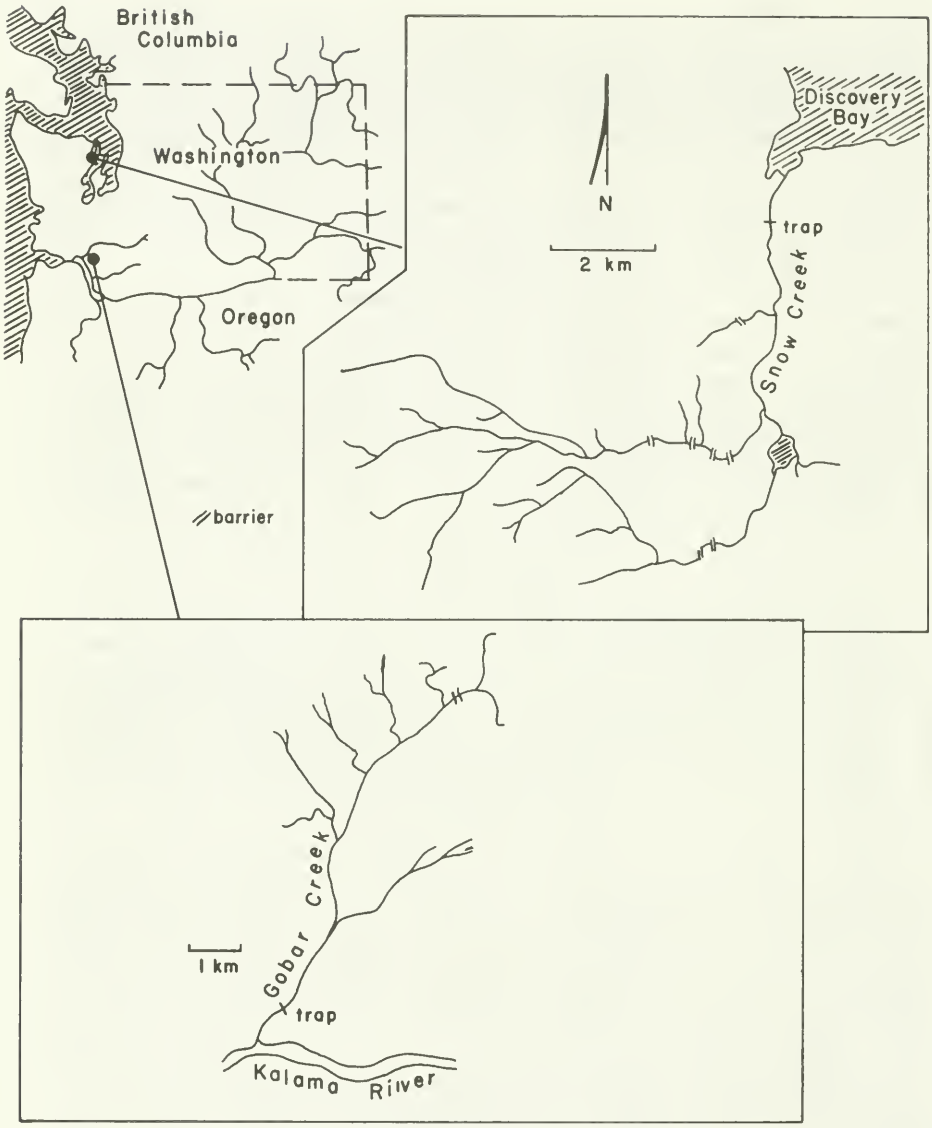

FIGURE 1. Map showing the location of Gobar Creek and Snow Creek sampling sites, Washington, 1978–1984.

upper reaches, respectively. Land directly adjacent to the lower area is largely agricultural with some residential development, whereas the upper watershed has had limited development except for periodic logging. Typical mean monthly flows during January and February range from 0.27 to 5.40 m^3/s and is 0.58 m^3/s during April and June. In August flows average 0.12 m^3/s. Mean monthly water temperatures range from 3.2°C in January to 15.6°C in August and average 10.6°C during April-June. Habitat composition and substrate is predominantly riffle-run-pool over gravel in the lower reaches (mouth to 1.6 km); riffle-pool-

run over gravel-rubble in the mid-reaches (1.6 km to 3.7 km); and cascade-pool over boulder-rubble-gravel in the upper reaches (5.3 km to 16.0 km). Riparian vegetation consists mainly of deciduous vegetative cover.

Fish species present are winter-run steelhead; coho salmon; chum salmon, *O. keta;* anadromous and resident cutthroat trout; Pacific lamprey; Western brook lamprey, *Lampetra richardsoni;* and sculpins, *Cottus* spp.

METHODS AND MATERIALS

Gobar Creek

From 1978 to 1981, downstream migrants were sampled in Gobar Creek using a stationary fyke net trap located 500 m above the confluence of Gobar Creek and the Kalama River (Figure 1). The trap was relocated in the spring of 1982 1 km farther upstream following a severe flood that destroyed the previous site as a trapping location. Sampling was terminated after 1984. Sampling was conducted two to five nights each week from mid-March to mid-June. From preliminary diel sampling in 1977, it was determined that few juvenile steelhead emigrated from Gobar Creek during daylight hours. In some areas, day time migrations of steelhead smolts have been observed (Chapman 1958). However, we believe this was not the case for Gobar Creek to any great extent. Accordingly, the trap was fished from sunset to sunrise of each sampling night. Since the trap blocked off the entire stream, we assumed the trap captured 100% of the migrants during the nights of operation. The net measured 1.2 m $\times$ 1.2 m at the opening and had 6.0 m $\times$ 1.2 m wings with 6.4 mm mesh.

We divided each sampling season into six, two-week intervals. The total number of Gobar Creek emigrants of each species and age group for each season was estimated using the following model:

$$\hat{N} = \sum_{j=1}^{6} A_j/a_j \left(\sum_{i=1}^{a_j} n_{ij} \right)$$

where,

$\hat{N}$ = total estimated number of emigrating juvenile migrants,

A_j = total number of days in the j^{th} sampling interval,

a_j = number of days actually sampled within the j^{th} interval and,

n_{ij} = number of individuals captured on the i^{th} night of the j^{th} interval.

Each season, we calculated the weighted average date of outmigration following methods in Leider, Chilcote, and Loch (1984).

For each sampling night, water temperatures were measured using a pocket thermometer and recorded.

Summer-run steelhead (hatchery and wild) account for about 83 percent of all steelhead spawners in Gobar Creek (Leider et al. 1984). Assuming equal juvenile survival between juvenile emigrant races was equal, Gobar Creek emigrants might be predominantly summer-run.

All steelhead captured were classified as either smolts or migrant parr based primarily on coloration and length. Smolts have external body silvering and fin margin blackening and parr retain their typical freshwater coloration patterns

(visible bar markings; non-silvery) (Loch, Chilcote, and Leider 1985). In addition, fork lengths (FL of parr were generally less than 110 mm, whereas smolts were longer. A weekly subsample of scales was collected from emigrating smolts for later age determination.

Snow Creek

A permanent fish trapping facility was constructed about one kilometre upstream from the mouth of Snow Creek in 1977 (Figure 1). The trap design enabled capture of fish greater than 300 mm FL year-round. Fish greater than 50 mm FL were captured when screens were installed during the start of the smolt emigration, in early March. Although this trap has been in operation continuously since its construction, only data from 1978 to 1984 were used for comparison to Gobar Creek trapping data.

Trapping efficiencies were measured by releasing large (90–150 mm FL) marked wild coho smolts upstream of the trap and recording the proportion of marked smolts recaptured. Trapping efficiencies ranged from 90–100%. Total number of emigrants was calculated as the total number of emigrants captured corrected by trapping efficiency.

Stream water level was monitored at the Snow Creek site by a Stevens Type F continuous float gauge. Rating curves were developed by measuring instantaneous stream discharge at various gauge levels with a Pygmy gurley meter and calculating a relationship to predict discharge for various gauge level readings. Water temperatures were recorded on a continuous reading Weathermeasure Model T 601A thermograph.

Captured steelhead were identified to be smolts or parr as described for Gobar Creek. A subsample of scales was collected from smolts as described for Gobar Creek.

RESULTS AND DISCUSSION

Yield

Although smolt yield in Gobar Creek was consistently less than in Snow Creek (Table 1), the opposite relationship was found for steelhead parr between streams. The mean number of steelhead parr migrants in Gobar Creek was 2,049 versus 334 in Snow Creek (Table 1). Of the total number of juvenile steelhead smolt and parr emigrating from Gobar Creek, an average of 86.1% were emigrant parr. In contrast, an average of 20.1% of the juvenile steelhead leaving Snow Creek were parr (Table 1).

TABLE 1. Estimated Number of Wild Downstream Migrant Steelhead from Gobar Creek and Snow Creek, 1978–1984.

	Year							
Migrant Group	*1978*	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*Mean*
Gobar Creek								
Smolt	349	571	301	316	222	465	90	331
Parr	933	3,034	2,201	1,966	1,908	3,323	975	2,049
Snow Creek								
Smolt	1,403	892	1,357	1,541	1,734	1,270	1,114	1,330
Parr	207	45	296	895	81	275	538	334

Differences in yield may partially be due to differences in stream gradient. Stream gradients were substantially lower in Gobar Creek compared to Snow

Creek. Johnson (1985) found higher steelhead parr densities in mainstem rivers in western Washington as gradient increased from 2.5 m/km to 30 m/km. He suggested that steeper gradients provided a greater abundance of preferred parr habitat. Similarly, Gard and Flittner (1974) suggested that gradients indirectly affect current pattern, pool to riffle ratios, bottom type, and water temperature, and influenced the distribution and abundance of fish in a California stream. However, Hartman and Gill (1968) suggest that gradients alone do not explain the abundance and distribution of juvenile steelhead within a gradient zone and that other factors related to environmental and biological processes are responsible. For example, low summer flows can reduce the potential for juvenile production within steep gradient zones. As water levels decrease, so does the living area available to juveniles, thereby increasing competition for reduced rearing territory and food. In Gobar Creek, a large percentage of migrants were parr, suggesting rearing territory for fish of that age was limited. Such juveniles unable to secure a territory may have been forced to relocate downstream to areas of less competition. In Snow Creek, a similar movement of juveniles out of rearing areas would necessitate them entering the marine environment. Chances of survival would be expected to be minimal because they would be physiologically ill-adapted for ocean life.

Timing

The emigration of Gobar Creek smolts generally began in late March, peaked by the first week of May, and ended in mid-June. In Snow Creek, downstream movement of smolts past the trap began in early April, peaked during the second week of May, and ceased by the end of June (Figure 2). Gobar Creek smolts emigrated an average of 7 days earlier than Snow Creek smolts ($P \leq 0.01$; paired t-Test). Although timing differences for each Gobar Creek age group were not statistically significant ($P \geq 0.05$; ANOVA), age 3 smolts usually moved downstream first, followed by age 2 smolts and then by age 1 smolts. In Snow Creek all three age groups tended to move downstream within the same time interval (Figure 2).

Size and age are important factors governing the outmigration timing of juvenile salmonids. Shapovalov and Taft (1954) observed that larger steelhead emigrated earlier than smaller smolts in a California stream. Stauffer (1972) and Kwain (1981) documented that older and larger juvenile rainbow trout of some Great Lakes tributary streams tended to migrate downstream earlier than smaller and younger juveniles. Likewise for Gobar Creek, the outmigration timing of steelhead smolts appeared to be related to size and age although for Snow Creek this was inconsistent.

The downstream migration of Gobar Creek parr began in early March, peaked within the second week of May, and ended by early June. In Snow Creek, the outmigration of parr usually began early March, peaked mid-May, and essentially was complete by the end of June (Figure 3). Gobar Creek parr emigrated significantly earlier by an average of 9 days than Snow Creek migrant parr ($P < 0.01$; paired t-Test).

It is possible that the normal outmigration patterns of juvenile salmonids may have been altered to some extent by the blocking of all or part of a stream by sampling devices. Such sampling biases are very difficult to detect and assess. In the present study, the effect of our sampling gear on juvenile downstream

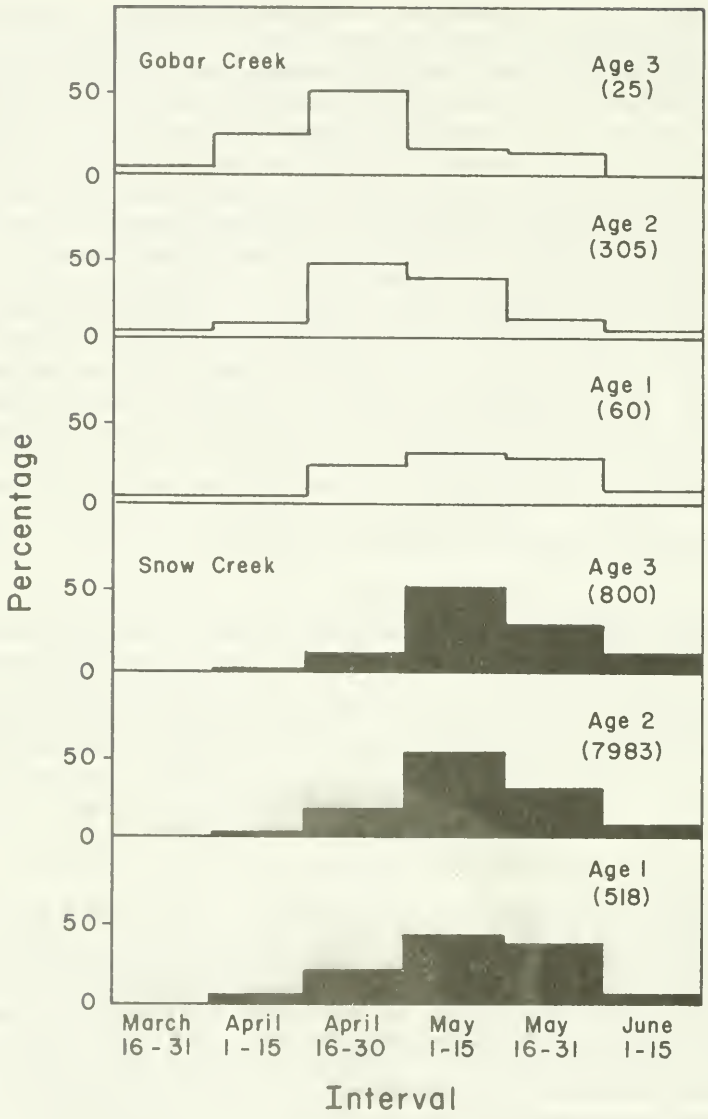

FIGURE 2. Mean temporal distribution, by age group, of emigrant steelhead smolts from Gobar Creek and Snow Creek, 1978 through 1984. Sample sizes are in parentheses.

migrant behavior was assumed to be negligible, and results between streams were comparable without adjustments.

Steelhead from our study streams may have evolved migratory strategies whereby expression of temporal differences is dependent on the outcome of tradeoffs between the energetic costs of protracted stream life (increased freshwater mortality) versus the potential benefits associated with larger size at outmigration (increased marine survival). If a population has either exceeded the carrying capacity of its habitat (e.g. over seeding) or had its habitat altered

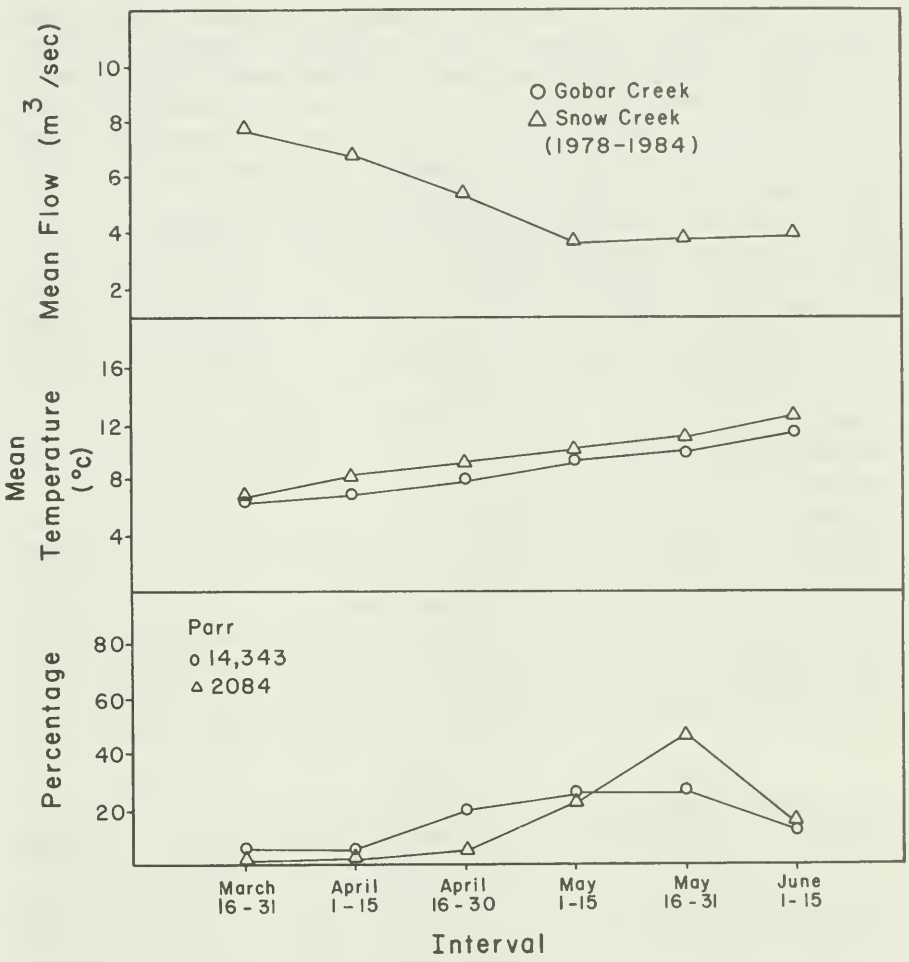

FIGURE 3. Mean temporal distribution of emigrant steelhead parr, water flow (Snow Creek), and water temperature by two week intervals for Gobar Creek and Snow Creek, 1978 through 1984.

(e.g. poor logging practices), freshwater mortality would be expected to increase. The relocation of parr to downstream areas may provide an adaptive mechanism to reduce freshwater mortality and provide the greatest possible survival of juveniles from each generation. This might be the case for Gobar Creek, where habitat and gradients may be more conducive to fry rearing than for parr rearing. In contrast, delayed emigration may provide more time for growth resulting in greater smolt-to-adult survival rates.

The timing of marine entrance by smolts migrating from Gobar Creek and Snow Creek may be similar. Trapped Snow Creek smolts must travel downstream a distance of only one kilometre before entering the saltwater at Discovery Bay, therefore peak marine entrance probably occurs near the time of peak trapping (mid-May). Gobar Creek smolts, however, must migrate 31 km to the confluence of the Kalama River and the Columbia River, and then another 135 km to the ocean. The seaward migration of steelhead smolts into

the lower Columbia River estuary peaks about the second week of May (Dawley et al. 1980, Dawley et al. 1981, Loch 1982). Dawley et al. (1981) estimated the average downstream movement rate of juvenile steelhead in the Columbia River to be 27 km/day. Smolts from Gobar Creek would have had to travel downstream approximately 21 km/day to have a similar marine entry time to that of Snow Creek smolts. This migration rate would compare favorably with that estimated by Dawley et al. (1981).

Environmental factors may also have influenced the downstream migration of juvenile steelhead in our study streams. Temperature affects many aspects of the smolting process, including the time at which smolts emigrate to the ocean (Wedemeyer et al. 1980, Schreck 1982). The downstream movement of Snow Creek steelhead migrants appears to be related to decreasing monthly water flow and increasing water temperature (Figure 3). However, substantial numbers of parr and smolts commonly emigrated during freshets. No flow information was available for Gobar Creek. Downstream movement, however, appeared to be associated with increasing water temperature (Figure 3). Solomon (1982) concluded that the emigration of juvenile Atlantic salmon, *S. salar*, was an active process dependent on the physiological state of juveniles as stimulated by environmental factors such as water temperature. Although Bjornn (1971), while working with photoperiod, found no direct relationship between timing of emigrating subyearling steelhead and increasing water temperature in an Idaho stream, he suggested that temperature may indirectly influence their movement. Wedemeyer et al. (1980) reported photoperiod does coordinate the physiological process of smoltification. However, water temperature acts as the controlling factor determining the rate of smoltification.

Size and Age

Mean lengths of smolts and parr were not the same between streams studied. Mean lengths of steelhead smolts in each age group were longer in Snow Creek than in Gobar Creek (Table 2). These differences were significant for age 3 smolts ($P < 0.05$; t-Test), and for the mean length of all smolts combined between Gobar Creek (156 mm FL; range 90 — 236 mm FL) and Snow Creek (165 mm FL; range 110 — 295 mm FL) ($P < 0.01$; t-Test). The mean length of Gobar Creek emigrant parr was significantly less ($P < 0.05$; t-Test) than Snow Creek emigrant parr. Mean length of emigrant parr in Gobar Creek was 86 mm FL (range 50 — 150 mm FL), whereas Snow Creek parr averaged 105 mm FL (range 76 — 140 mm FL)(Figure 4). Differences in sub-sampling procedures, growth rates, stream-specific age structures or brood survival rates may have produced these inequities.

Most steelhead smolts emigrated at age 2 in both Gobar Creek and Snow Creek. However, the mean percentages of age 1 and age 3 smolts differed between locations (Table 2). In other studies of winter-run steelhead, Gudjonsson (1946), Chapman (1958) and Wagner, Wallace, and Campbell (1963) also reported a predominance of age 2 steelhead smolts and a percentage of age 3 smolts at least twice that of the age 1 smolts (Table 2).

Since age at smoltification can be size (growth) related (Hoar 1976), the age composition differences we observed between Gobar Creek and Snow Creek may reflect differential rearing conditions and growth rates. Differences in age structure may also be associated with the presence of summer-run fish.

Summer-run steelhead typically spawn at least one month before winter-run steelhead in Gobar Creek (Leider et al. 1984). Their young will probably emerge from the gravel earlier than winter-run steelhead. Therefore, summer-run steelhead may produce offspring with a relative size difference that persist to the smolt stage.

It is unlikely that many parr leaving Gobar Creek in the spring immigrated back into the creek during the fall-winter period. Although immigration of steelhead juveniles can contribute substantially to the number of parr and smolts emigrating from tributaries the following spring (Bustard and Narver 1975, Cederholm and Scarlett 1982), this occurrence has been shown to be minimal in Gobar Creek (Leider et al. 1986b).

TABLE 2. Comparison of Mean Smolt Age Data for Steelhead in Several West Coast Streams.

Stream	*Age (yr.)*	*Mean Length (mm)*	*Percent*	*Race* [a]	*Data Source*
Babine r., B.C.	1	—	0.0	S	Narver (1969)[b]
	2	—	2.0		
	3	—	82.0		
	4	—	15.0		
Chilliwack R., B.C.	1	111	2.0	W	Maher and Larkin (1955)[b]
	2	165	62.1		
	3	200	35.4		
Minter Ck., Washington	1	—	3.0	W	Gudjonsson (1946)
	2	—	85.0		
	3	—	12.0		
Hoh R., Washington	1	—	3.5	W	Larson & Ward (1954)
	2	—	89.9		
	3	—	7.4		
Snow Ck., Washington	1	132	5.3	W	This study
	2	162	86.3		
	3	195	8.4		
Gobar Ck., Washington	1	128	15.8	W/S	This study
	2	159	76.7		
	3	178	7.5		
Kalama R., Washington	1	142	6.1	W/S	Loch et al. (1985)
	2	161	80.6		
	3	172	13.3		
Alsea R., Oregon	1	—	5.0	W	Chapman (1958)
	2	—	82.0		
	3	—	13.0		
Alsea R., Oregon	1	—	1.0	W	Wagner et al. (1968)
	2	—	87.0		
	3	—	12.0		
Rogue R., Oregon	1	—	6.0	S	Everest (1973) [b]
	2	—	70.0		
	3	—	23.0		
Waddell Ck., California	1	—	10.1	W	Withler (1966)[b]
	2	—	72.3		
	3	—	16.7		
	4	—	0.9		

[a] W = Winter-run; S = Summer-run

[b]Backcalculated from scales sampled from mature adults.

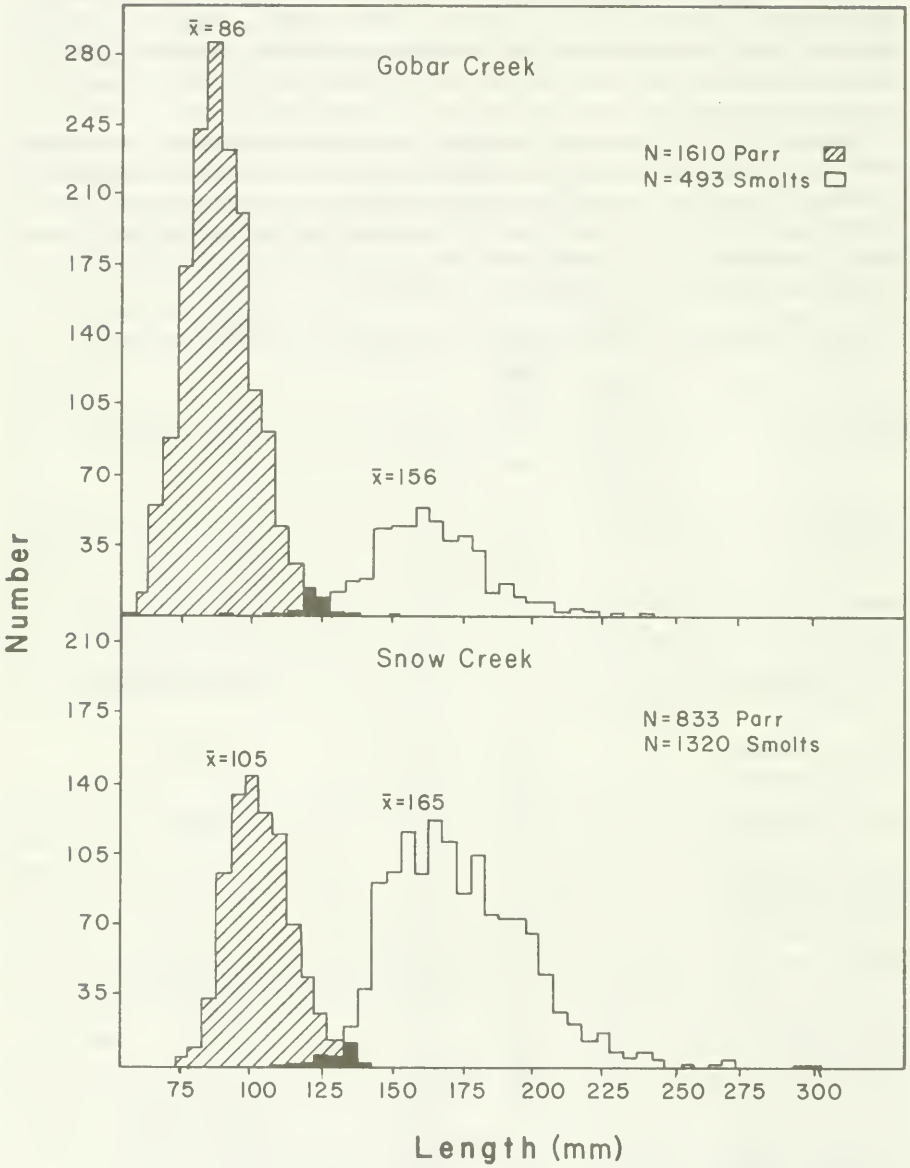

FIGURE 4. Length frequency histogram of migrant steelhead smolts and parr from Gobar Creek and Snow Creek, 1978 through 1984. Black area represents overlap in length frequency between smolts and parr.

Management Implication

In practical terms, simply enumerating tributary smolt run sizes may not give an accurate indication of that stream's relative ability to produce anadromous fish. Migrant parr may be a major part of the total emigration from a tributary and a substantial proportion may survive to become smolts. If these fish are

overlooked, then the total smolt contribution from a specific tributary may be underestimated. In Gobar Creek, most of the emigrant parr which survived to become smolts are believed to have reared either within the mainstem Kalama River or in some other lower Kalama River tributary (Leider, Chilcote, and Loch 1986b). Tredger (1980) suggested that 69% of the steelhead smolt yield from a tributary in a British Columbia river system may have been pre-smolt emigrants to mainstem areas. In contrast, substantial survival of emigrant parr from Snow Creek is doubtful because of the limited downstream habitat and direct encounter with the marine environment prior to physiological readiness. This is supported by the observation that few adults returning to Snow Creek had lived only one year in freshwater as juveniles (Washington Department of Wildlife, unpublished report).

Further attention should be given to the interactions of salmonids in tributary-mainstem complexes. There is a need for a river system approach to fishery management and habitat protection since the same steelhead juvenile may use both mainstem and tributary areas during freshwater life cycle.

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ALLOZYME VARIATION IN THE CALIFORNIA HALIBUT, *PARALICHTHYS CALIFORNICUS* [1]

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Adult California halibut, *Paralichthys californicus,* collected from the vicinity of Marina del Rey, Los Angeles, and juveniles collected from Mission Bay, San Diego, were surveyed electrophoretically for genetically encoded protein variation. One-fourth of the 38 protein-coding loci proved to be polymorphic and on average an individual was heterozygous at 5.2% of the loci; these levels of genetic variation are typical of flatfishes. Discovery of marked divergences between the two samples in allelic frequencies at two loci is surprising, given the presumed dispersal potential of the pelagic larvae of this species. Alternative hypotheses to explain this result are testable. That the collection of juveniles appears not to be a sample of genotypes from a randomly mating population calls attention to the importance of understanding the process of recruitment in interpreting both these particular results and the impact of hatchery enhancement efforts.

INTRODUCTION

Legislation (AB1414) in 1984 created the Ocean Resources Enhancement and Hatchery Program within the California Department of Fish and Game for the purpose of examing the feasibility of enhancing populations of white seabass, *Atractoscion nobilis,* and California halibut, *Paralichthys californicus.* Under this program, a project was undertaken to examine whether genetically coded enzyme polymorphisms might be useful in describing the structures of natural populations of these species and whether such electrophoretically detectable enzyme variants might serve as genetic tags of hatchery-reared stocks. The amount of enzyme variation uncovered in the preliminary study of California halibut suggests that gel electrophoresis could be useful on both counts for this species. Moreover, our discovery of substantial variation between two populations within the southern California Bight suggests that the natural population of California halibut in this region is subdivided. The cause of this subdivision is problematical given what is known of the life history of this species.

The California halibut is distributed in the near shore from northern Washington to southern Baja California, being particularly concentrated in the southern California Bight region (Frey 1971, Methot 1983). Spawning, following an onshore migration of adults (Clark 1931), takes place from January through October with slight peaks in spring and possibly fall. Pelagic eggs and larvae occur primarily inshore (Ahlstrom and Moser 1975, Gruber, Ahlstrom and

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Mullin 1982). Barnett et al. (1984) suggest that larvae may exert some control over their movements inasmuch as older larvae appear to be more concentrated in the nearshore zone than younger larvae. Nevertheless, as pelagic larval development requires 20 to 30 days, there appears ample opportunity for considerable dispersal before the 9–10 mm juvenile recruits to the benthos of bays or estuaries which are the primary nursery habitats (Haaker 1975, Plummer, DeMartini and Roberts 1983). Except for offshore emigration from these embayments upon reaching sexual maturity, juveniles and small adults are remarkably sedentary as demonstrated by mark and recapture studies (Frey 1971, Haaker 1975). Despite these sedentary habits, however, the protracted spawning season, the dispersal potential of pelagic eggs and larvae, and the long distance dispersal exhibited by some large adults (Frey 1971) suggest that natural populations of California halibut ought to be well mixed at least throughout the southern California Bight.

MATERIALS AND METHODS

Samples of California halibut were obtained from two sources: (i) Mission Bay (MIS), San Diego, CA., in October, 1985 (N=30) and (ii) a halibut derby held at Marina del Rey (MAR), Los Angeles, CA., in April, 1986 (N=90). The first sample comprised juvenile fish ranging in size from approximately 10 to 22 cm total length which were taken in trawls, frozen immediately in an ultracold freezer and later transported to the Bodega Marine Laboratory where they were stored at −70° C. The second sample consisted of tissue samples dissected from derby catches that ranged in size from 41 to 92.5 cm standard length. These tissue samples were kept on ice during the derby, then frozen at −20° C for transport to the Bodega Marine Laboratory where they were stored at −70° C until processing for electrophoretic analysis.

Tissues dissected for electrophoretic analyses were eye, heart, kidney, liver and muscle. The day before electrophoresis, whole frozen juvenile fish and derby specimens were slowly thawed. Tissues were dissected from the juvenile fish, and both these and the derby specimens were then homegenized in 0.5M Tris-HC1, pH 7.1 and re-frozen overnight in covered plastic well-trays at −70° C. On the day of electrophoresis, samples were allowed to thaw slowly on ice.

Methods for horizontal starch-gel electrophoresis, protein assays and genetic interpretation of zymograms were substantially the same as those described by Ayala et al. (1973) and Tracey et al. (1975). The protocol used to separate and resolve 21 enzymes and proteins is summarized in Table 1. Proteins are referred to by the capitalized abbreviations given in Table 1, loci by these same abbreviations italicized in upper and lower case with numerical suffixes denoting isozymes in order of increasing anodal migration, and alleles by italicized numerals that express absolute differences in millimeters of electrophoretic separation between variants and the most common electromorphs observed for each protein. Alleles encoding common electromorphs are arbitrarily designated *100*. Specimens from both population samples were included in every electrophoretic run so that repeated comparisons of the relative mobilities of their allozymes could be made.

TABLE 1. Enzymes and Proteins Resolved in an Electrophoretic Survey of Gene-Protein Variation in the California Halibut.

Enzyme or protein	*E.C. No.*	*Buffer*[1]	*Tissue*[2]	*Number of Loci*
aconitate hydratase (ACON)	4.2.1.3	D	L	1
aspartate aminotransferase (AAT)	2.6.1.1	A	H,M	1
creatine kinase (CK)	2.7.3.2	C	E	3
esterase (EST)	3.1.1.1	A,E	L,K+M	2
fructose biphosphatase (FBP)	3.1.3.11	D	L	1
fumarate hydratase (FUM)	4.2.1.2	D	L	1
glucose-6-phosphate isomerase (GPI)	5.3.1.9	A,E	M,L	2
glyceraldehyde-phosphate dehydrogenase (GAPDH)	1.2.1.12	C	E,K	1
isocitrate dehydrogenase (IDH)	1.1.1.42	C	L,H	1
lactate dehydrogenase (LDH)	1.1.1.27	B	E+H+M	3
malate dehydrogenase (MDH)	1.1.1.37	D	M	2
peptidase (PEP)				
L-glycyl-L-leucine (GL)	3.4.13.11	A	L	1
L-leucyl-L-glycyl-L-glycine (LGG)	3.4.13.11	A	L	1
L-phenylalanyl-L-proline (PP)	3.4.13.9	A	L	1
phosphoglucomutase (PGM)	2.7.5.1	A,E	L	3
phosphogluconate dehydrogenase (PGDH)	1.1.1.44	C	L,K	1
protein (PROT)		A	H+M	9
purine nucleoside phosphorylase (PNP)	2.4.2.1	C	L	1
superoxide dismutase (SOD)	1.15.1.1	B	L	1
xanthine dehydrogenase (XDH)	1.1.1.204	B	L	1
xylulose reductase (XRD)	1.1.1.10	A	L	1
TOTALS: 21 Enzymes or Proteins				38 Loci

[1] Buffers A, B, C and D are given by Tracey et al. (1975); buffer E is the amino-propylmorpholine citrate system of Clayton and Tretiak (1972).

[2] Tissues: E = eye, H = heart, L = liver, K = kidney, M = skeletal muscle.

Single-individual genotypes were re-coded as alphabetical characters and submitted to the BIOSYS-1 program of Swofford and Selander (1981) for calculations of allelic frequencies, average proportions of heterozygous individuals per locus (observed, H_o, and expected [unbiased estimate of Nei (1978)] H_e), proportions of loci polymorphic (P, where a locus is considered polymorphic if the frequency of the most common allele does not exceed 0.99), goodness-of-fit tests to Hardy-Weinberg-Castle equilibrium genotypic proportions using Levene's (1949) correction for small sample size, F-statistics and Nei's (1978) unbiased measure of genetic similarity. Log-likelihood ratio (G) tests of differences in allelic frequencies between the two population samples were calculated from absolute frequencies after appropriate pooling of rare alleles.

RESULTS

A total of 38 discrete zones of activity or staining are resolved on starch-gel zymograms assayed for the 21 proteins listed in Table 1. Of these zones, 23 are each represented by a single band in all of the fish examined (CK-1, CK-3, EST-1, FBP, FUM, GAPDH, IDH, LDH-1, LDH-3, PEP-GL, PGDH, PGM-3, nine PROTs, SOD and XRD); each of these proteins is inferred to be encoded by a single, monomorphic locus.

The remaining 15 proteins (ACON, AAT, CK-2, EST-5, GPI-1 and -2, LDH-2, MDH-1 and -2, PEP-LGG, PEP-PP, PGM-1 and -2, PNP and XDH) exhibit electrophoretic variation in at least one individual. Phenotypes of presumptive heterozygotes at the loci inferred to encode these proteins generally conform to

those expected on the basis of known enzyme subunit structures (Harris and Hopkinson 1976, Ruth and Wold 1976, Koehn and Eanes 1978). In particular, phenotypes for AAT, GPI, MDH, PEP, and PGM and their genetic interpretations are substantially as described by Grant et al. (1983) for yellowfin sole, *Limanda aspera*, and by Grant, Teel and Kobayashi (1984) for Pacific halibut, *Hippoglossus stenolepis*. Relative allelic frequencies, heterozygosities and sample sizes for the loci encoding these polymorphic enzymes are presented for each of the two populations sampled (Table 2).

Three measures of genetic variation are computed from the allelic frequency data for each of the two populations: average number of alleles per locus, proportion of loci polymorphic, and average proportion of loci heretorozygous per individual (Table 3). The two populations appear to be significantly different for the first measure, Mission Bay having only 1.3 ± 0.1 alleles per locus *vs.* 1.7 ± 0.2 for the Marina del Rey sample. A *t*-test for paired comparisons of the numbers of alleles at the 15 polymorphic loci yields $t = 2.236$, 14 d.f., $p < 0.05$. Except, however, for the *Xdh* locus, which is represented by nine alleles in MAR *vs.* only three alleles in MIS, the difference in numbers of alleles between the two population samples is attributable to rare alleles in the larger MAR sample. Eliminating alleles that have a frequency of 0.01 or less in the MAR sample, the paired comparisons test yields a nonsignificant $t = 1.169$.

The two populations are each polymorphic for about one-fourth of the loci surveyed in this study ($P = 0.24$ and 0.26 for MIS and MAR, respectively), but they share polymorphisms at only six loci (*Est-5, Ldh-2, Mdh-2, Pgm-1, Pgm-2* and *Xdh)*. The MIS sample is polymorphic at three loci that are monomorphic in MAR (*Aat, Mdh-1,* and *Pnp*), while the MAR sample is polymorphic for four loci that are monomorphic in MIS (*Acon, Gpi-1, Gpi-2* and *Pep-pp*). (*Ck-2* and *Pep-lgg* each have one rare allele in the MAR sample and are thus not counted as polymorphic under the definition adopted.)

Sampling error for average heterozygosity is less sensitive to the numbers of individuals studies than to the number of loci surveyed (Nei, 1978). The two populations are not significantly different for H_o or H_e (0.046 *vs.* 0.058 for MIS and MAR, respectively; Table 3). As further confirmation that the MIS sample does not have less heterozygosity than the MAR sample, a paired *t*-test of single-locus expected heterozygosity values (transformed by $\sin^{-1}\sqrt{H}$) for the 15 polymorphic loci yields a nonsignificant $t = -0.94$ (14 d.f., $0.3 < p < 0.4$). Averaged over all individuals from both populations, heterozygosity in the California halibut is 5.2%.

Sample sizes and levels of variation at six of the eight polymorphic loci in the MIS sample are too low to permit goodness-of-fit tests between observed phenotypic proportions and those expected under random mating. For the remaining two loci, *Pgm-2* and *Xdh,* alleles were pooled into common (*100*) and rare allelic classes; χ^2 tests (1 d.f.) show agreement between observed and expected phenotypic proportions for PGM-2 ($\chi^2 = 0.001$, $p = 0.97$), but a significant departure for XDH ($\chi^2 = 12.81$, $p < 0.001$). Wright's fixation index (F_{IS}) is negative for eight of nine polymorphic loci (heterozygote excess) but is significantly positive for the *Xdh* locus (heterozygote deficiency). For the

TABLE 2. Allelic Frequencies and Observed Proportions of Heterozygotes *(H)* at 15 Polymorphic Loci in Samples of California Halibut (N Individuals) from Mission Bay (MIS) and Marina del Rey (MAR), California.

Locus	Population MIS	MAR
Aat		
(N)	30	90
96	0.02	0.00
100	0.98	1.00
H	0.03	0.00
Acon		
(N)	4	90
95	0.00	0.02
100	1.00	0.96
103	0.00	0.02
H	0.00	0.08
Ck-2		
(N)	30	90
92	0.00	0.10
100	1.00	0.99
H	0.00	0.01
Est-5		
(N)	29	88
100	0.15	0.51
103	0.85	0.49
H	0.31	0.57

Locus	Population MIS	MAR
Gpi-1		
(N)	25	90
92	0.00	0.01
100	1.00	0.97
108	0.00	0.02
H	0.00	0.07
Gpi-2		
(N)	30	90
97	0.00	0.01
98	0.00	0.01
100	1.00	0.98
H	0.00	0.02
Ldh-2		
(N)	30	90
93	0.02	0.01
100	0.98	0.98
107	0.00	0.01
H	0.03	0.03
Mdh-1		
(N)	30	90
92	0.03	0.00
100	0.97	1.00
H	0.07	0.00

Locus	Population MIS	MAR
Mdh-2		
(N)	30	89
92	0.75	0.88
100	0.25	0.12
H	0.50	0.20
Pep-lgg		
(N)	30	90
100	1.00	0.99
103	0.00	0.01
H	0.00	0.01
Pep-pp		
(N)	30	89
97	0.00	0.02
100	1.00	0.98
H	0.00	0.03
Pnp		
N	29	30
96	0.06	0.00
100	0.94	1.00
H	0.12	0.00

Locus	Population MIS	MAR
Pgm-1		
(N)	29	90
96	0.02	0.05
100	0.98	0.94
104	0.00	0.01
H	0.03	0.11
Pgm-2		
(N)	30	83
96	0.00	0.01
98	0.05	0.00
100	0.73	0.84
102	0.22	0.14
103	0.00	0.01
H	0.43	0.29
Xdh		
(N)	30	73
92	0.00	0.07
93	0.00	0.12
94	0.00	0.11
95	0.15	0.25
96	0.00	0.15
97	0.08	0.12
98	0.00	0.14
99	0.00	0.01
100	0.77	0.03
H	0.23	0.78

Marina del Rey sample, goodness-of-fit tests are possible for *Est-5* ($\chi^2 = 1.52$, 1 d.f., $p = 0.22$), *Pgm-2* (following pooling into common and rare allelic classes, $\chi^2 = 0.01$, 1 d.f., $p = 0.92$) and *Xdh* (with pooling, $\chi^2 = 0.05$, 1 d.f., $p = 0.83$). Inspection of observed and expected phenotypic frequencies at the remaining nine polymorphic loci in this sample reveals close agreement, with fixation indices ranging from −0.053 to 0.066. To summarize, with the single exception of the *Xdh* locus in the MIS sample, observed phenotypic porportions conform to those expected under random mating within California halibut populations.

Table 3. Genetic Variability at 38 Loci in Two Samples of California Halibut. See Text for Definitions of Genetic Statistics. Sample Sizes per Locus Are Average Numbers of Individuals. Values in Parentheses Are Standard Errors.

Population	*Mean Sample Size per Locus*	*Mean No. of Alleles per Locus*	*Percentage of Loci Polymorphic*	*Mean Heterozygosity*	
				Obs.	*Exp.*
Mission Bay	28.0	1.29	23.7	0.046	0.046
	(0.7)	(0.1)		(0.019)	(0.019)
Marina del Rey	82.8	1.68	26.3	0.058	0.058
	(3.0)	(0.2)		(0.026)	(0.027)

The genetic similarity of the Mission Bay and Marina del Rey population samples averaged over all 38 allozyme- and protein-coding loci is high, with Nei's (1978) unbiased $I = 0.985$. This overall similarity, however, belies substantial divergences of allelic frequencies at two loci, *Est-5* and *Xdh* (Table 2). Wright's measure of standardized allelic frequency variance, the ratio of observed variance between localities to maximum variance for the mean allelic frequencies at a locus, is 0.134 and 0.197 for the *Est-5* and *Xdh* loci, respectively. For the remaining 13 polymorphic loci, F_{ST} ranges from 0.0 to 0.014, with an average of only 0.002 (mean calculated using angular transformed values). Log likelihood ratio tests of the independence of allelic frequency and locality are possible at the six loci polymorphic in both populations. Not surprisingly, the G values for *Est-5* (24.87, 1 d.f.) and *Xdh* (126.80, 2 d.f.) are highly significant, $p \ll 0.001$ for both tests. Allelic frequencies at the *Mdh-2* locus are also significantly dependent upon locality ($G = 5.03$, 1 d.f., $p < 0.05$), even though F_{ST} for this locus is only 0.014. Allelic frequencies at the *Ldh-2, Pgm-1* and *Pgm-2* loci are independent of locality.

DISCUSSION

Electrophoretic separation and assay of soluble enzymes and proteins from tissues of the California halibut reveals substantial genetic variation. One-fourth of the 38 proteins studied are polymorphic, and the average individual is heterozygous at 5.2% of these loci. These results may be compared with data compiled by Smith and Fujio (1982) from published and unpublished electrophoretic studies of 29 species of flatfishes. Because general proteins are highly conservative in fishes, particularly in the Pleuronectiformes, these authors recommend using an average heterozygosity based only on enzyme-coding loci in making comparisons among species that have been assayed for varying numbers of protein-coding loci. For the California halibut, average observed heterozygosity is 6.8% over 29 enzyme-coding loci. From Smith and Fujio's (1982) Table 1 we calculate, using angular transformation, that average

observed enzyme heterozygosity for 29 flatfishes is 8.1% with a 95% confidence range from 5.1% to 9.8%. Thus, the California halibut has a level of genetic diversity that is typical of flatfishes. This abundant genetic variation should prove useful in the management of California halibut hatcheries and in the unambiguous, genetic tagging of hatchery releases (Hedgecock 1977).

The surprising result of this study is the marked divergence of allelic frequencies at the *Est-5* and *Xdh* loci between localities separated by a distance of only about 200 km. This geographic differentiation contrasts sharply with the homogeneity observed over distances of thousands of kilometers in other flatfish species (Grant et al. 1983, 1984) and marine fishes in general (Gyllensten 1985). Although formal genetic studies have not been made, we are confident of our genetic interpretations of these enzyme polymorphisms for two reasons: (1) The phenotypes or zymogram patterns themselves are similar to those shown to be under genetic control in other species; and (2) there is good agreement of observed and expected phenotypic frequencies in the large sample of adult fish from Marina del Rey.

Assuming, then, that these two enzyme polymorphisms are indeed genetically determined, what factors might account for the divergence of allelic frequencies between the two localities sampled? Four alternative, but not mutually exclusive, hypotheses require further testing:

(i) Genetic differences between these conspecific populations have accumulated by random sampling processes (genetic drift) in the absence of strong selection and gene flow (Wright 1931). This seems unlikely given the dispersal potential of the pelagic larvae, but Burton (1983) and Hedgecock (1986) have argued that actual gene flow cannot be inferred from presumed dispersal potential of pelagic larvae.

(ii) The genetic differences are historical in origin, and the California halibut population of the southern California Bight has not yet returned to the homogeneous, equilibrium expected with large population sizes and high gene flow.

(iii) The genetic differences are the result of diversifying selection acting on the loci in question or upon closely linked loci. Transplantation or hatchery release experiments might provide critical data on the survival of alternative genotypes in different localities. If the genetic differences are adaptive, hatchery enhancement efforts should match released genotypes to environments in order to increase the chances of success and possibly to avoid compromising the genetic adaptations of natural stocks.

(iv) The genetic differences are the result of sampling different stages in the life cycle of the organism. We have compared juveniles from Mission Bay with adults from Marina del Rey. Were those juveniles representative of the adult halibut population in the San Diego area? If the juveniles were representative of the adult population, then we are left with the three hypotheses above to explain the differentiation of adult halibut populations. There is indication in our data, however, that the juvenile population on the Mission Bay nursery ground may have represented only a small sample of the reproductive output of the adult population. The only significant departure from randomly mating phenotypic proportions detected in this study was the distribution of *Xdh* genotypes in the MIS sample. Moreover, there is a highly significant, non-random association of genotypes between the *Est-5* and *Xdh* loci in the Mission Bay

sample ($G = 21.7$, 1 d.f., $p \ll 0.001$; Table 4A), but not in the Marina del Rey sample ($G = 8.22$, 4d.f., $0.1 > p > 0.05$; Table 4B). A parsimonious explanation for these results is that the juveniles collected from Mission Bay may have represented a limited number of sibling groups.

TABLE 4. Associations of Genotypes at the *Est-5* and *Xdh* Loci in Samples of California Halibut from (A) Mission Bay, California, and (B) Marina del Rey, California.

A. Mission Bay

Xdh genotypes	*Est-5* genotypes		
	100/103	*103/103*	*totals*
100/100	1	19	20
95/95, 97/97, 95/97, 95/100	8	1	9
totals	9	20	29

$G = 21.7$, 1 d.f.

B. Marina del Rey

Xdh genotypes	*Est-5* genotypes			
	100/100	*100/103*	*103/103*	*totals*
95/95	1	1	2	4
95/non-*95*	6	15	8	29
non-*95*/non-*95*	12	27	3	42
totals	19	43	13	75

$G = 8.22$, 4 d.f.

Further electrophoretic study of California halibut populations in the southern California Bight region are clearly needed to distinguish among the four explanations of our preliminary results. The intriguing suggestion that familial structure may be detectable among the juveniles on nursery grounds holds considerable promise for detailed studies of recruitment processes in this economically important species.

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BOOK REVIEWS

STRESS AND PERFORMANCE IN DIVING

By Arthur J. Bachrach and Glen H. Egstrom, Best Publishing Co., San Pedro, CA, 1987, 183 p., illustrated. $26.50

It has long been acknowledged that most diving fatalities occur as a direct result of problems created by the divers themselves, rather than external factors such as equipment failure or marine life. Analysis of individual accidents, on a case by case basis, almost invariably lead the perceptive researcher to conclude that stress is at the central core of each of these incidents. With this thesis in mind, Egstrom and Bachrach proceed through an exhaustive examination of the various elements which contribute to diver stress and ultimately, diving accidents.

The authors' vast experience, Egstrom at UCLA and Bachrach at the Naval Medical Research Institute, is evident throughout this text. Indeed, they have been at the forefront of the research on diver performance for more than twenty years. This work is, essentially, a brief synopsis of the span of their studies.

The book is well organized, proceeding from defining stress, through stress indicators, and detailing panic and panic reactions. Serious attention has also been given to identifying the role of diver training and intelligent equipment evaluation as they relate to diver performance. There are 28 figures, 10 tables, and 5 diagrams.

Although the introduction of this book purports this work to be directed at the sport diving community, this reader found it extremely technical and probably beyond the scope of the average sport diving enthusiast. It is an excellent book for the diving instructor, the diving physiologist, or members of the scientific diving community.

—Kristine Henderson

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