

acclimation temperature of 8°C, ΔT of 13°C, and exposures varying from 1 to 6 h. Depending on age, mortality ranged between 60 and 100%. The oldest larvae experienced total mortality. Hoss et al. (1974) compared the field-collected larvae of three species of flounder (*Paralichthys dentatus*, *P. lethostigma*, and *P. albigutta*) with the larvae of Atlantic menhaden, *Brevortia tyrannus*; spot, *Leiostomus xanthurus*; and pinfish, *Lagodon rhomboides*, and found the flounders most resistant. The flounders acclimated to 15°C withstood a thermal shock of 18°C for periods of 40 min with a survival rate of 30%.

The results of a number of studies (e.g., Schubel et al. 1978) indicate that resistance to thermal shock is age-dependent, with yolk-sac larvae being more tolerant than postyolk-sac larvae. Power plants should be designed and operated to sustain the most sensitive developmental stages of ichthyoplankton. Tests similar to the one described here should be made before site-specific tests are performed and before design and operating criteria are set. Sublethal effects, although not considered in this paper, should also be considered in the establishment of the excess temperature that will be utilized in a given season. Such sublethal effects reduce the chances of survival by entrained ichthyoplankton.

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MOVEMENTS OF ROCKFISH (*SEBASTES*) TAGGED IN NORTHERN PUGET SOUND, WASHINGTON

Recreational scuba divers and hook-and-line fishermen in northern Puget Sound (Fig. 1) have taken an annual catch of 150,000 bottomfish of all species; four species of Pacific rockfish (*Sebastes*) account for about 70% of the catch (Washington Department of Fisheries 1977-1980). These four species are copper rockfish, *S. caurinus*; quillback rockfish, *S. maliger*; black rockfish, *S. melanops*; and yellowtail rockfish,

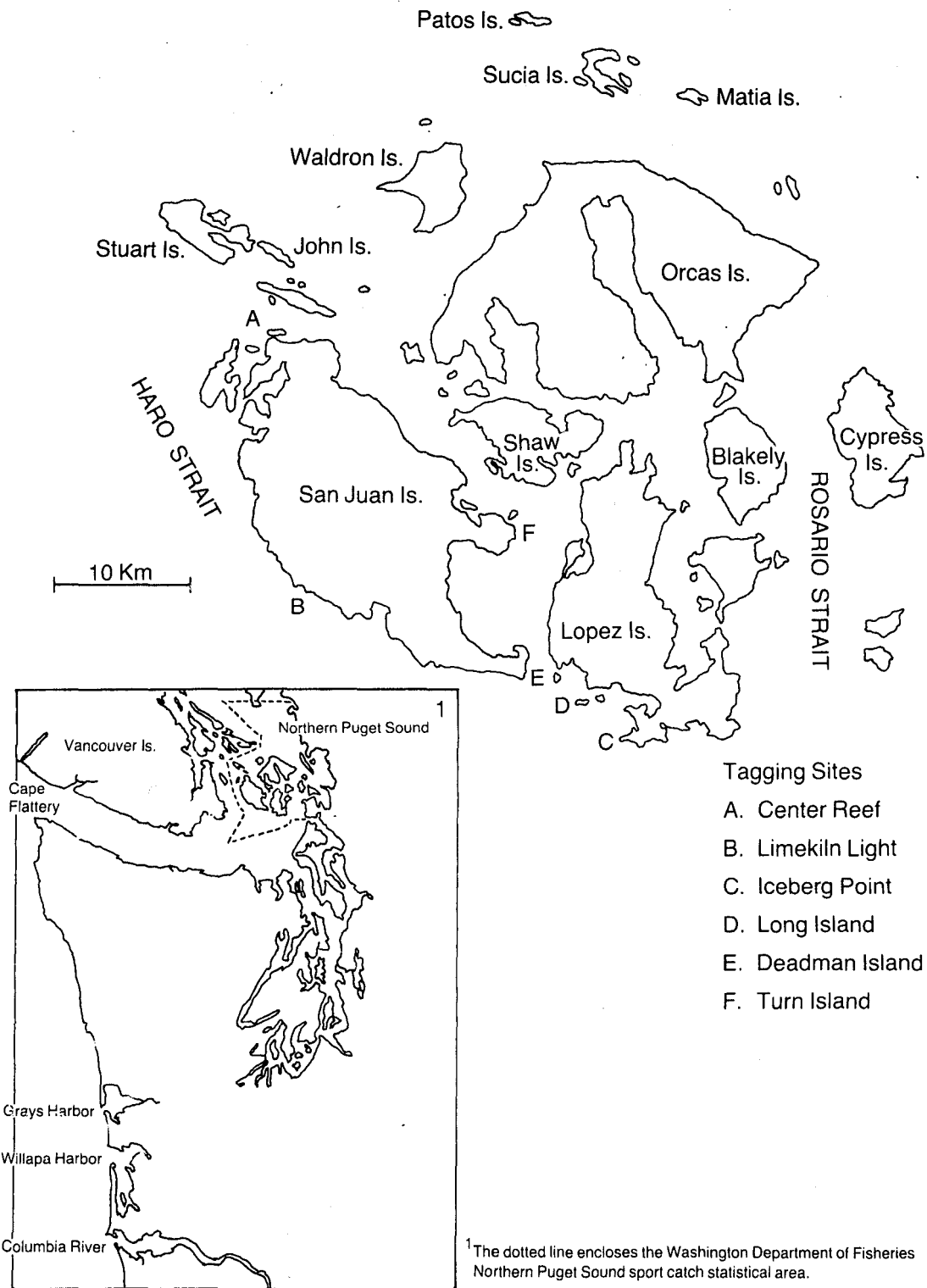


FIGURE 1.—San Juan Islands and rockfish tagging areas. Inset shows location of tagging area in relation to the Washington coast.

S. flavidus. There is also a commercial catch of these four species in northern Puget Sound by set net, long-line, troll, and trawl gears, but the commercial catch of rockfish in northern Puget Sound is minor compared with the recreational catch (Petersen and DiDonato 1982).

All four species occur from California to Alaska (Hart 1973). In Washington, copper and quillback rockfish tend to be shallow-water, inlet inhabitants associated with nearshore reefs and rockpiles (Alverson et al. 1964; Patten 1973; Hart 1973). Black and yellowtail rockfish, although they are most abundant offshore in the ocean to depths of 400 m, are common in inlets such as Puget Sound where they are usually associated with shorelines or shallow rockpiles (Hart 1973). In northern Puget Sound, copper and quillback rockfish are usually caught on the bottom. Black and yellowtail rockfish tend to associate with the bottom, but are often caught well up in the water column, sometimes at the surface. Moulton (1977) observed the depth distribution of these four species in northern Puget Sound by scuba diving. All four species occurred in depths to 30 m, the deepest of Moulton's dives, although copper, black, and yellowtail rockfish were rarely seen below 22.5 m. The average depths of the individuals observed by Moulton during the months April-September were about 7.5 m for black and yellowtail rockfish, 12.5 m for copper rockfish, and 22.5 m for quillback rockfish. Moulton indicated that all four species may be distributed somewhat deeper in winter than in summer.

All Pacific rockfish are live-bearers (Phillips 1964). Those species most sought by commercial and sport fishermen are characterized by relatively long life and slow growth (Phillips 1964; Westheim and Harling 1975; Beamish 1979; Boehlert 1980; Fraidenburg 1980). The maturation age (age by which 50% are mature) of yellowtail rockfish off California is 5 yr (Phillips 1964), whereas off Washington it is 8 and 10 yr for male and female yellowtail rockfish, respectively (Gunderson et al. 1980). Maturation age for both sexes of copper rockfish in Puget Sound is 4 yr (Patten 1973), 5 and 6 yr for black rockfish males and females, respectively, off central Oregon (McClure 1982), and 5 yr for both sexes of quillback rockfish in Puget Sound (Gowan 1983).

Relatively few studies on the movements of tagged Pacific rockfish were done. Carlson and Haight (1972) tagged yellowtail rockfish in southeast Alaska to study homing behavior. Coombs (1979) tagged blue rockfish, *S. mystinus*; yelloweye rockfish, *S. ruberrimus*; and black rockfish on a reef near Depoe Bay, Oreg., to determine if these species were resi-

dent or transient on the reef. Gowan (1983) tagged copper, yellowtail, black, and brown, *S. auriculatus*, rockfish in central Puget Sound (near Seattle) to learn about their movements and harvest rates. The Washington Department of Fisheries tagged black rockfish off the central Washington coast near Westport in 1981 and 1982 to study their movements (B. Culver¹).

Our tagging study, supported by the University of Washington Sea Grant program, was initiated in response to public concern expressed to the Washington Department of Fisheries that certain heavily fished reefs in northern Puget Sound were becoming depleted of rockfish. Our intent was to determine the extent of the differences in migratory behavior among rockfish species most commonly caught. A species for which there is little migration of individuals once they reach a fishable size could be depleted more easily on popular fishing reefs by overfishing than a species in which the fishable-sized individuals are migratory; therefore, a sedentary species might need more restrictive fishing regulations than a migratory one.

Methods

Between July 1975 and June 1977, a total of 700 rockfish were tagged and released at six popular fishing sites in the San Juan Islands (Fig. 1). The tag used is the Floy² anchor tag with orange colored vinyl tubing (Floy FD67 "spaghetti" tag with #20 tubing). This tag is inserted below the dorsal fin, following the method of Dell (1968). In addition to releasing tagged fish, we also held a lot of rockfish in an aquarium for 2 yr to observe tag retention and behavior of tagged fish. This lot consisted of 10 fish that were caught, handled, and tagged similarly to the fish tagged and released.

Numbers tagged (by species) were 82 copper rockfish, 342 quillback rockfish, 123 black rockfish, and 153 yellowtail rockfish. The method of capture for tagging was by hook-and-line with conventional angling techniques. The fish were brought aboard singly and placed in a cradle for hook removal, measuring, and tagging. These activities were completed as quickly and gently as possible, and the fish were released within about 2 min from time of capture. Only fish that appeared lively, were relatively uninjured by the hook, and had no external indications of decompression stress were tagged. We restricted

¹B. Culver, Washington Department of Fisheries, Montesano, WA 98563, pers. commun. October 1982.

²Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

the depths of capture for tagging to 30 m or less. Rockfish caught from depths >30 m usually showed signs of decompression stress, such as loss of equilibrium and eversion of the stomach from swim bladder expansion.

Rockfish suffering from decompression stress can be successfully treated by releasing gases from the swim bladder or behind the eye with a hypodermic needle (Gotshall 1964). Before doing any tagging, we deflated swim bladders of 10 quillback rockfish using Gotshall's technique and held them in an aquarium. All died within 3 mo. Although we are uncertain if all deaths were from decompression stress, we decided to tag fish only from relatively shallow depths, avoiding deflation of the swim bladder.

For tag recoveries, we relied upon voluntary returns from anglers, scuba divers, and commercial fishermen. To encourage the returns a \$2.00 reward was paid for each return, posters advertising the program and the rewards were placed at appropriate locations, and informational reply letters were sent to those who returned the tags. If incomplete recapture information accompanied a returned tag, we would attempt to contact the individual who had caught the fish in order to complete the record.

During the tagging period we sacrificed a total of 389 rockfish specimens to determine sex and state of maturity from external gonadal inspection and age from surface reading of otoliths. It was our intent that the sacrificed fish be representative of the tagged lots. We fulfilled this intent by systematically allocating our field effort between tagging and collection of samples for sacrifice. At each tagging site we would alternate between days for tagging and days for sacrificing. On one day, all fish caught would be tagged; the next day at this site all would be sacrificed—this procedure was followed for the duration of the study.

Results and Discussion

Tag Retention

The lot held to observe tag retention consisted of 6 copper, 3 quillback, and 1 black rockfish. After 4 mo, no fish had died or lost tags, and the tag insertion points on the body looked well healed. During the following 20 mo, 1 copper and 3 quillback rockfish died, but this was not, in any way apparent, due to tagging. None of the dead fish showed any necrosis around the tag insertion point, and the tags on all dead fish were well imbedded, intact, and readable. When the retention experiment was terminated after 24 mo, the 6 rockfish that were still alive showed no ill

effects from the tags, and the tags were well imbedded, intact, and readable.

Composition of Sacrificed Lots

Copper and quillback rockfish tended to be mature and relatively old individuals (Table 1). Sex ratios of these two species were not significantly different from 50:50. On the average, black rockfish were younger than the previous two species, but all the sacrificed fish were mature. There was a significant predominance of male black rockfish over females ($\chi^2 = 5.4, 1 \text{ df}, P < 0.05$). Yellowtail rockfish tended to be younger than any of the previous species ($\bar{x} = 5.3 \text{ yr}$) and all were immature. The sexes of the yellowtail rockfish were indistinguishable based on external inspection of gonads.

TABLE 1.—Age, length, sex, and maturity composition of samples of four species of rockfish collected by hook-and-line concurrently with tagging efforts in the San Juan Islands, Wash., during the period July 1975-June 1977. Also shown are means and standard deviations of lengths of samples of these species from the recreational scuba diver and boat angler catch in the San Juan Islands, 1979-80.

	Copper rockfish	Quillback rockfish	Black rockfish	Yellowtail rockfish
<i>n</i>	199	155	60	115
Total length (cm)				
\bar{x}	35.5	34.3	41.0	34.2
range	24-57	22-45	23-54	25-42
SD	9.2	5.5	6.0	3.8
Age, yr ¹				
\bar{x}	11.7	14.2	7.4	5.3
range	5-34	5-37	3-14	3-7
% male: % female	54:44	46:54	65:35	unknown
% mature	100.0	98.3	100.0	00.0
Total lengths from 1979-80 recreational catch (cm ²)				
<i>n</i>	233	354	62	56
\bar{x}	34.4	37.2	37.0	33.9
SD	6.8	5.6	6.7	3.0

¹For copper and quillback rockfish ages, the means and upper limits may be too low. Surface readings of otoliths were used for aging which may underestimate ages of rockfish older than about 22 yr according to Beamish (1979).

²Source: LaRiviere, M. G., and G. G. Bargmann. 1982. The fisheries for bottomfish by scuba divers and recreational anglers in the San Juan Islands during 1979 and 1980. Prog. Rep. Wash., Dep. Fish., Mar. Fish. Sect. (Draft).

Composition of Tagged Lots

The mean lengths of the tagged lots of copper, quillback, and yellowtail rockfish (Table 2) conformed closely to those of the respective sacrificed lots. It is therefore reasonable to assume that virtually all the tagged copper and quillback rockfish were mature and that all the tagged yellowtail rockfish were immature. The tagged black rockfish lot averaged less in length than the sacrificed lot for no apparent reason other than random sampling effects (36.0 cm vs. 41.0 cm), and may therefore have included some immature individuals. McClure (1982) indicated that 5-yr-old male and 6-yr-old

TABLE 2.—Tag and recapture data for four species of rockfish tagged in the San Juan Islands, Wash., during the period July 1975-June 1977.

	Copper rockfish	Quillback rockfish	Black rockfish	Yellowtail rockfish
No. tagged and released	82	342	123	153
Total lengths at tagging (cm)				
\bar{x}	33.4	32.5	36.0	34.7
range	24-49	20-46	23-55	21-44
SD	4.5	5.7	6.4	4.5
Number recaptured at				
release site	11	11	5	2
near release site	0	1	0	0
open ocean	0	0	3	8
total	11	12	8	10
% of tagged fish recaptured	13.4	3.2	6.5	6.5
Number of days between date tagged and date recaptured				
\bar{x}	614	457	908	982
range	2-1,844	31-1,913	8-2,207	18-2,214
Mean lengths of recaptured fish at time of tagging (cm)	31.4	31.8	36.1	34.7

female black rockfish off central Oregon (the respective ages by which 50% are mature) averaged about 34 and 36 cm, respectively.

The means and standard deviations of the sacrificed lots were similar to those in the 1979-80 recreational catch, species by species (Table 1). Accordingly, we would conclude that the recreational catch of copper, quillback, and black rockfish consists mostly of mature individuals, whereas the yellowtail rockfish catch tends to be immature individuals.

Tag Recoveries

Numbers of recoveries by general area of recapture are listed in Table 2. Each of the 11 copper rockfish recoveries was recaptured at its release site, which we define as the area within 300 m of the exact point of release, according to our knowledge of the extent of each fishing reef and judgment of the accuracy of geographical specificity by fishermen who returned tags. All tagging sites are well-known fishing areas with ready geographic reference points. Length of time between date of tagging and date of recapture for copper rockfish varied from 2 to 1,844 d, averaging 614 d.

Ten of 11 quillback rockfish recoveries were at the release sites; the other recovery was caught about 2.8 km from the release point. The latter fish was initially caught over a shallow reef, but released into much deeper water as the boat drifted off the reef. A fish so released may find it difficult to navigate back to its "homesite" as was postulated similarly for yellowtail rockfish in Carlson and Haight's (1972) homesite study. Length of time between tagging and recapture of quillback rockfish ranged from 31 to 1,913 d, averaging 457 d.

Our findings indicate that mature copper and quillback rockfish roam very little. It is possible that they migrate seasonably from the homesites, but this seems unlikely since times of year of recoveries appeared to be random relative to times of year of tagging. Four copper rockfish tagged in the summer (August and September) were recaptured during winter months (January-March); four quillback rockfish tagged in the summer were recaptured during February and March.

Mature-sized copper rockfish were tagged near Bainbridge Island (central Puget Sound) by the National Marine Fisheries Service from 1975 to 1979. All recoveries, 75 of 554 tagged fish, indicated, as did ours, that there was no roaming from the tagging site (Gowan 1983).

An explanation for our higher recapture rate for copper rockfish, 13.4%, compared with that of quillback rockfish, 3.2% ($\chi^2 = 15.9$, 1 df, $P < 0.01$), is that copper rockfish tend to occupy shallower waters than quillback rockfish and are therefore more susceptible to scuba divers and anglers, who fish in depths of 20 m or less primarily for rockfish.

Of 8 recoveries from 123 black rockfish tagged, 5 were recaptured at their release sites and 3 were recaptured off the Washington coast between Willapa Harbor (360 km from the release site) and the Columbia River mouth (400 km). The time between release and recapture ranged from 8 to 829 d for black rockfish recaptured at their release sites and from 703 to 2,207 d for those recaptured offshore.

The Washington Department of Fisheries tagged a total of 6,913 adult black rockfish near Westport, Wash., in the summer of 1981 and spring of 1982. Of 77 recoveries to date, 53 were caught near release site, but the remainder migrated southward as far as

the Columbia River mouth, 40 km from the release site (B. Culver footnote 1). Coombs (1979) reported that a tagged black rockfish migrated 619 km, from the central Oregon coast northward to Puget Sound.

Eight out of 10 recoveries from 153 tagged yellowtail rockfish indicated that there is a pattern of inshore to offshore migration. Seven recoveries were off the Washington coast, from Cape Flattery (144 km from the release site) to Willapa Harbor, and one was recaptured from Queen Charlotte Sound, B.C. The latter recovery, however, could have been caught near Cape Flattery, since it was recovered by a U.S. trawler that fished both the Cape Flattery and Queen Charlotte grounds on the same trip. The time between release and recapture ranged from 58 to 2,214 d for the 8 yellowtail rockfish recaptured offshore. The other two recoveries of tagged yellowtail rockfish were at the tagging site, one 18 d and the other 1,194 d after tagging.

The movement of yellowtail rockfish from Puget Sound to the open coast may concur with time of maturation. According to our observations, the population of this species in northern Puget Sound apparently consists of immature individuals of 7 yr or younger in contrast to the other three species tagged for which the individuals recruited to the fisheries are apparently mostly mature. Moulton (1977) and Gowan (1983) found only immature yellowtail rockfish in Puget Sound. Commercial trawl catches of yellowtail rockfish off the Washington coast contain mostly older (>7 yr) individuals than those found in Puget Sound, and the coastal catch is mostly adults according to length-maturity relationships (Gundersen et al. 1980), length-at-age relationships (Fraidenburg 1980), and age composition of offshore catches (Fraidenburg 1981).

Tagged yellowtail rockfish in inside waters of southeast Alaska showed strong homing tendencies, returning to site of first capture when experimentally displaced as far as 22.5 km (Carlson and Haight 1972). The reported ages of fish tagged in this home-site study were 7-16 yr, and many or all could have been mature. Carlson and Haight labeled them as adults in the title of their paper.

Our evidence supports the contention that yellowtail rockfish in Puget Sound are immature and migratory, heading for the ocean before maturation. Traits of adopting, adhering to, or returning to home-sites may become firmly developed only after maturation. The probable mechanism maintaining Puget Sound populations is drift or migration from the ocean of juveniles spawned offshore. W. Lenarz³ believed there is a similar pattern for brown rockfish in San Francisco Bay; there they are virtually all

juveniles, ages 5 or younger, leaving inshore waters before onset of maturity (age 6 or 7).

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