Movements of tagged adult yellowtail rockfish, *Sebastes flavidus*, off the west coast of North America

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The Department of Fisheries and Oceans, Canada, and the University of Alaska conducted independent tagging studies on yellowtail rockfish, *Sebastes flavidus*, in the early 1980's. The Canadian study was designed to validate ageing methodology for rockfishes (Leaman and Nagtegaal, 1987). The Alaskan study was part of a larger survey of nearshore bottomfish resources in southeastern Alaska.[1,2] While neither study was designed to quantify the extent of this species' movement, the recoveries provided new insight into rockfish behavior and new implications for the management of this species.

Tagging studies of shallow demersal (<100 m) species of rockfish, *Sebastes* spp., have typically indicated very limited movement (Table 1), with the exception of a report of a brown rockfish, *S. auriculatus*, that travelled over 50 km from San Francisco Bay.[3] Authors have also suggested limited movement for the deeper demersal or "slope" rockfish species, such as Pacific ocean perch, *S. alutus*, that are found along the continental slope at depths greater than 200 m (Fadeev, 1968; Gunderson, 1971; Wishard et al., 1980; Leaman and Kabata, 1987). While they appear to make seasonal bathymetric migrations, the available evidence from commercial fishing patterns, parasite occurrence, and age/size compositions have led investigators to hypothesize that these species make very limited latitudinal movements along the continental shelf. However, because of decompression and other injuries associated with surfacing from depths of over 200 m, no tagging studies have been performed to test this hypothesis.

It is the semi-pelagic species that inhabit the continental shelf (100–200 m) which appear to exhibit significant movement. Studies of black rockfish, *S. melanops*, and immature yellowtail rockfish indicate that at least some individuals move long distances. In northern Puget Sound (Fig. 1), Mathews and Barker (1983) tagged 123 black and 153 yellowtail rockfish. Three of eight black rockfish and eight of 10 confirmed yellowtail rockfish recoveries came from the west coast of Washington at distances up to 400 km from the release site. Because the yellowtail rockfish were all immature, the authors proposed an ontogenetic movement offshore in conjunction with reproductive maturation. Similarly, Barss[4] reported that 12 of 23 recovered immature canary rockfish, *S. pinniger*, travelled more than 100 km along the Oregon coast. Culver (1987) provided the first evidence of long distance movement of adult or reproductively mature rockfish. He recovered 484 tags from 14,795 black rockfish tagged off Washington and northern Oregon. One fish, which had been tagged off Oregon, was recovered off northern California, 555 km south of its release site. More than 12% of the recovered black rockfish moved farther than 80 km.

Contrary to those reports, which documented long distance move-

[1] Rosenthal, R. J., L. J. Field, and D. Meyer. 1981. Survey of nearshore bottomfish in the outside waters of southeastern Alaska. Alaska Coastal Research, P. O. Box 368, Langley WA, 98260. Final report to State of Alaska, Dep. Fish Game, Comm. Fish. Div. Juneau, 84 p.

[2] Rosenthal, R. J., L. Haldorson, L. J. Field, and V. M. O'Connell. 1982. Inshore and shallow offshore bottomfish resources in the southeastern Gulf of Alaska. Alaska Coastal Research, P. O. Box 368, Langley WA, 98260. Final report to State of Alaska, Dep. Fish Game, Comm. Fish. Div. Juneau, 166 p.

[3] Lenarz, W. Tiburon Laboratory, Nat. Mar. Fish. Serv., CA 94920. Personal commun., March 1993.

[4] Barss, B. Marine Science Center, Oregon Dept. Fish. Wildl., Newport, OR 97365. Personal commun., December 1985.

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ment, studies of blue rockfish, *S. mystinus* (Miller and Geibel, 1973) and olive rockfish, *S. serranoides* (Love, 1980), as well as other studies of yellowtail rockfish (Carlson and Haight, 1972; Pearcy, 1992), indicate much more limited movement. In fact, dispersal from the tagging site was so limited in the latter two studies that the authors hypothesized that yellowtail rockfish have strong homing tendencies and exhibit site fidelity. However, these two studies were conducted over limited spatial and temporal scales.

The purpose of this note is to examine the hypothesis of limited versus extensive movement of yellowtail rockfish. We use data from our two studies, which cover a broader time and space coverage than those studies that implied limited movement. We present the details of the 42 recaptures, discuss some of the factors which may have influenced the overall likelihood of recapture, and conclude with a comment on the management implications of the results.

Table 1

Reports of rockfish, *Sebastes spp.*, movement.

Species	No. of recoveries	Max. dist. moved, (km)	Literature cited
Demersal species			
Black-and-yellow rockfish,			
S. chrysomelas	38	<1	Larson, 1980
Brown rockfish,			
S. auriculatus	22[1]	<1	Matthews et al., 1987
	16	<2	Hartmann, 1987
	1	>50	Lenarz, footnote 3 in text
	11	<2	Gowan, 1983
China rockfish,			
S. nebulosus	13	<1	McElderry, 1979
Copper rockfish,			
S. caurinus	[2]	[2]	Gascon and Miller, 1981
	11[1]	<1	Mathews and Barker, 1983
	29	<1	Matthews et al., 1987
	16	<3	Hartmann, 1987
	75	<3	Gowan, 1983
Gopher rockfish,			
S. carnatus	49	<1	Larson, 1980
Quillback rockfish,			
S. maliger	12	<3	Mathews and Barker, 1983
	28[1]	<1	Matthews et al., 1987
Yelloweye rockfish,			
S. ruberrimus	7	<1	Coombs, 1979
	3	<1	O'Connell, 1991
Semi-pelagic species			
Black rockfish,			
S. melanops	61	<1	McElderry, 1979
	40	<50	Gowan, 1983
	8	400	Mathews and Barker, 1983
	484	555	Culver, 1987
	9	619	Coombs, 1979
Blue rockfish,			
S. mystinus	168	24	Miller and Geibel, 1973
	98	43	Hartmann, 1987
Bocaccio			
S. paucispinis	66	148	Hartmann, 1987
Olive rockfish,			
S. serranoides	435	<33	Hartmann, 1987
Vermilion rockfish,			
S. miniatus	1	10	Turner et al., 1969
Yellowtail rockfish,			
S. flavidus	76	<23	Carlson and Haight, 1972
	10	144	Mathews and Barker, 1983
	25	<4	Pearcy, 1992

[1] Repeated dive observations of tagged fish.
[2] Tagged fish showed strong site fidelity, no numbers provided.

Methods

Methodology used in the Canadian program, which was conducted from 1980 to 1982, has been described in detail (Shaw et al., 1981). The primary area of tagging was off southwest Vancouver Island; additional tagging was performed in Queen Charlotte Sound (Figs. 2 and 3). Fish were captured by trawl at depths of 70–80 m over bottom depths of 110–130 m. Prior to tagging, all fish were anaesthetized with tricaine methanesulphonate (MS-222). Fish with hyperinflated swim bladders were deflated with a hypodermic needle to remove excess gas (Gotshall, 1964), measured to the nearest cm (fork length), and tagged with an external Floy anchor tag imbedded in the dorsal musculature between the pterygiophores. Most fish were injected with oxytetracycline (OTC) (50 mg/kg body wt.) (Leaman and Nagtegaal, 1987). All fish were held for one hour in covered tanks with a continuous flow of seawater. Fish from the last haul of each day were held overnight. Condition after tagging and after release was assessed by using a numerical index based on several categories of injuries (Shaw et al., 1981). We did not record sex of released specimens but did examine

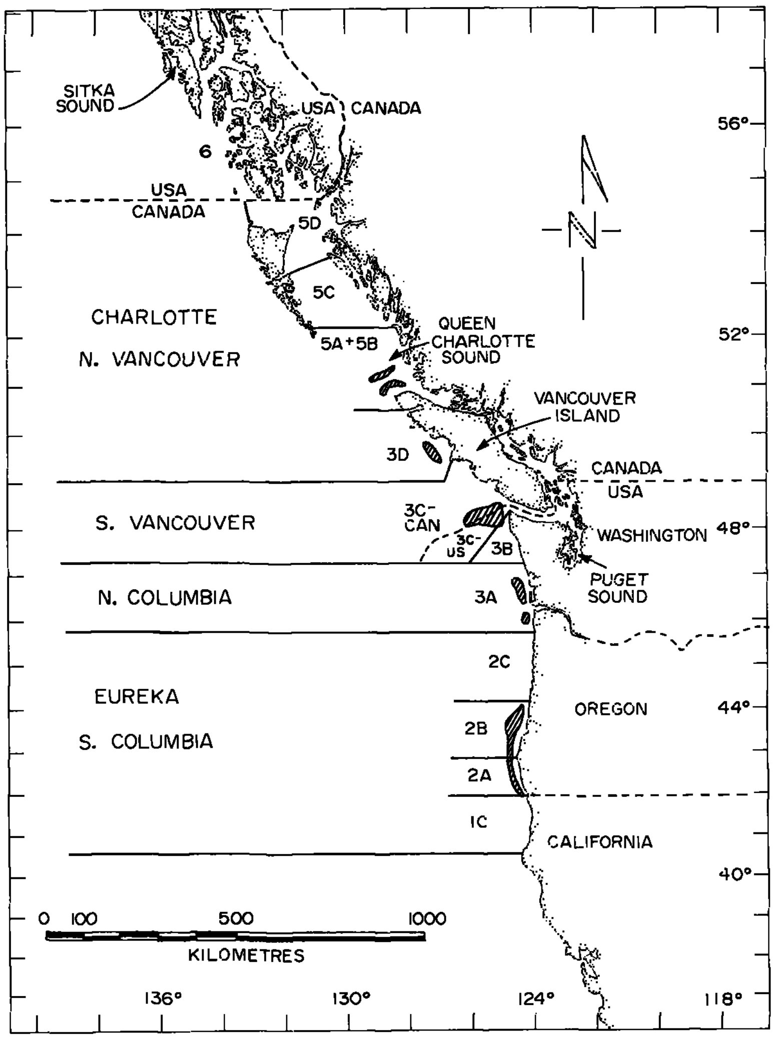

Figure 1

Sites of major yellowtail rockfish, *Sebastes flavidus*, fishing grounds (hatched areas); stock designations are based on individual or combinations of International North Pacific Fishery Commission (INPFC) statistical areas (ie. N. Columbia) and Pacific States Marine Fishery Commission (PSMFC) statistical boundaries within the INPFC areas (ie. 3C-US).

two samples of 100 fish sacrificed during the 1980 tagging off the southwest coast of Vancouver Island.

In the Alaskan program of 1981 and 1982, fish were caught by hook and line from depths of 40–100 m with commercial jigging machines. Fish were examined for decompression stress and hooking damage. Only those fish with no visible stress symptoms were tagged. A total of 397 yellowtail rockfish were tagged as in the Canadian study, but none was injected with OTC or decompressed. All fish were captured and released in July 1982 at two sites in Sitka Sound, Alaska (Fig. 2).

All tag recoveries from both programs were obtained from commercial fisheries. Data on gender and recovery location were obtained when possible, although the latter information was usually limited to statistical area. We calculated the minimum possible distance travelled by assuming the fish travelled a direct course approximating the edge of the continental shelf. Distance was calculated to the border of the statistical area closest to the point of release and rounded down to the nearest 25-km interval. Transit time was calculated as the overall distance divided by the number of days at large. The recovery ratios (number recovered divided by number released) for the two studies were compared with a two-tailed test of binomial proportions (Kalbfleisch, 1976). We used maturity ogives from Tagart (1991) to infer the proportion mature for specific lengths. He reported 50% maturity at 39.6 cm and 45.4 cm for males and females, respectively, for fish from northern Washington.

We conducted a linear regression of the natural log of number recovered against time (0.5 years–9.5 years) for the Canadian releases to derive a point estimate of the instantaneous annual rate of extinction.

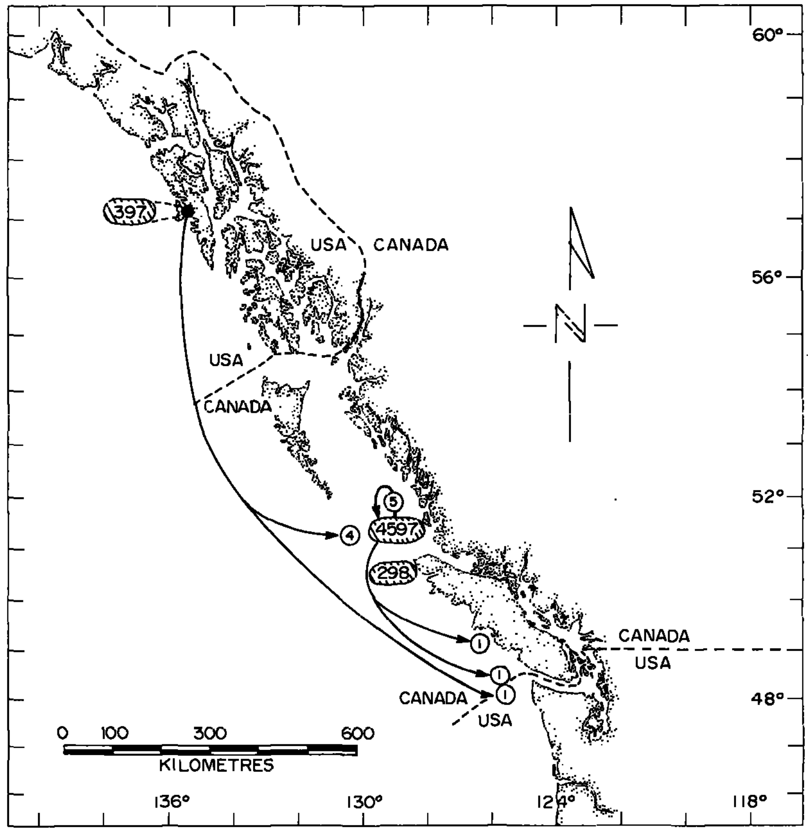

Figure 2

Number of releases (in hatched areas) and recoveries (in circles) of yellowtail rockfish, *Sebastes flavidus*, tagged in southeast Alaska and Queen Charlotte Sound.

Results

Canadian-tagged fish

The Canadian program tagged and released 4,895 fish off central British Columbia (B.C.) and 9,557 off southern B.C. and northern Washington waters. Thirty-seven have been recovered, all from commercial catches from Oregon, Washington, and B.C. waters (Figs. 2 and 3; Table 2). Of these, 36 were accompanied by reliable information on recapture location. Twenty-seven of the 36 (75%), moved less than or equal to 25 km from the release location. However, among the nine fish that travelled more than 25 km, three moved at least 100 km, three others at least 125 km, and one at least 250 km. The farthest displacements of Canadian-tagged fish were one fish that moved from Queen Charlotte Sound to the southwest coast of Vancouver Island (400 km) and one that moved from southwest Vancouver Island to southern Oregon (400 km). The most rapid movements from original tagging sites were two recoveries of Canadian-tagged fish that moved from the north coast of Washington to northern Oregon. One travelled at least 100 km in 73 days (1.37 km/day) whereas the other travelled at least 125 km in 100 days (1.25 km/day).

Average fork length of Canadian-tagged fish was 44.5 cm (23–58 cm). Recovered specimens averaged 45.9 cm (33–54 cm). Among the 21 recoveries for which sex was known, only two were probably immature at the time of release, based on their sex and lengths. Among the nine individuals that travelled further than 25 km, we know the sex of seven. Of these, only one, a 33-cm male, was likely to have been immature at the time of release.

The rate of recoveries from the Canadian study gradually declined over time (Table 3). The point estimate of the instantaneous annual rate of extinction was 0.2. However, the 95% confidence range (0.099–0.307) was wide, reflecting the low number of recoveries.

Alaskan-tagged fish

Of the 397 yellowtail rockfish tagged in Alaska, five have been recovered. All five travelled south to B.C. or to Washington waters over distances of 425–1400 km. The fish were tagged in 1982 but were not recovered until at least 1987. Time at liberty ranged from 1,827 to 2,842 days. The opportunity for recovery of yellowtail rockfish in southeastern Alaska commercial fisheries was limited. The total reported commercial catch in 1991 was three tons; the sport catch was negligible.[5] However, the recovery ratio of Alas-

[5] O'Connell, V. Alaska Dept. Fish Game, Sitka, AK 99835. Personal commun., February 1991.

Table 2

Recoveries of tagged yellowtail rockfish, *Sebastes flavidus*, by the Department of Fisheries and Oceans, Canada, and the University of Alaska; Figure 1 indicates Pacific States Marine Fish Commission Areas (PSMFC); "—" indicates that no information was obtained.

PSMFC area of tagging	PSMFC area of recovery	Days at liberty	Minimum distance displaced (km)	Length at release (cm)	Length at recovery (km)	Injuries at release	Age at recovery (yr)	Sex
Canadian								
3C-US	3B	838	0	44	44	none	15	—
3C-US	3C-US	>3,617	0	44	45	none	—	M
3C-US	3A-3D[1]	N/A	N/A	54	N/A	none	—	—
3C-US	3A	859	125	51	53	none	15	F
3C-US	3C-US	2,577	0	54	N/A	none	—	—
3C-US	3C-US	48	0	53	53	none	—	—
3C-US	3C-US	434	25	46	N/A	bleeding[2]	—	—
3C-US	3C-US	55	0	52	54	none	—	—
3C-US	3C-US	382	0	45	N/A	none	—	—
3C-US	3C-US	2,268	0	45	49	none	—	M
3C-US	3C-US	18	0	43	48	none	—	—
3C-US	4A	1,392	25	45	48	none	—	—
3C-US	3C-US	478	25	47	N/A	none	—	—
3C-CAN	3A	832	125	45	45	loss of scales	13	F
5A+5B	3C-US	1,279	400	42	43	bleeding[3]	11	M
5A+5B	5A+5B	861	25	45	46	none	13	M
5A+5B	3D	3,215	250	42	43	none	—	M
5A+5B	5A+5B	2,119	0	44	48	bleeding[4]	—	M
5A+5B	5A+5B	328	25	46	45	none	20	M
5A+5B	5A+5B	3,219	0	48	48	none	—	M
5A+5B	5A+5B	624	0	51	50	loss of scales	17	M
3C-US	3C-?	1,177	0	49	48	none	—	—
3C-US	2B	690	400	48	45	none	9	F
3C-US	3C-US	73	0	47	N/A	none	—	—
3C-US	3A	798	100	33	39	none	—	M
3C-US	3B	1,218	0	41	46	none	—	M
3C-US	3B	186	0	42	41	none	—	M
3C-US	3A	73	100	46	46	none	—	—
3C-US	3C-US	1,472	0	47	47	none	—	M
3C-US	3A	1,994	100	46	N/A	none	—	—
3C-US	3B	739	0	47	46	none	34	M
3C-US	3C-US	877	0	50	51	none	17	F
3C-US	3C-US	N/A	25	41	39	bruised	—	—
3C-US	3B	1,231	0	48	N/A	none	—	—
3C-US	3C	2,653	0	42	49	none	—	F
3C-US	3A	103	125	42	42	none	—	M
4A	3B	2,438	0	43	46	none	—	M
Alaskan								
SE Alaska	5A+5B	1,827	700	37	45	—	—	—
SE Alaska	3B	2,047	1,400	37	45	—	—	—
SE Alaska	5A+5B	2,842[5]	750	32	N/A	—	—	—
SE Alaska	5A+5B	2,722[6]	625	33	45	—	—	M
SE Alaska	5A+5B	2,729[7]	N/A	41	50	—	—	F

[1] Recovered from Area 3A, 3B, 3C, or 3D.
[2] Bleeding at tag site.
[3] Bleeding at de-gassing site.
[4] Bleeding at oxytetracycline injection site.
[5] 2,842–2,872 days at liberty.
[6] 2,722–3,087 days at liberty.
[7] 2,729–3,094 days at liberty.

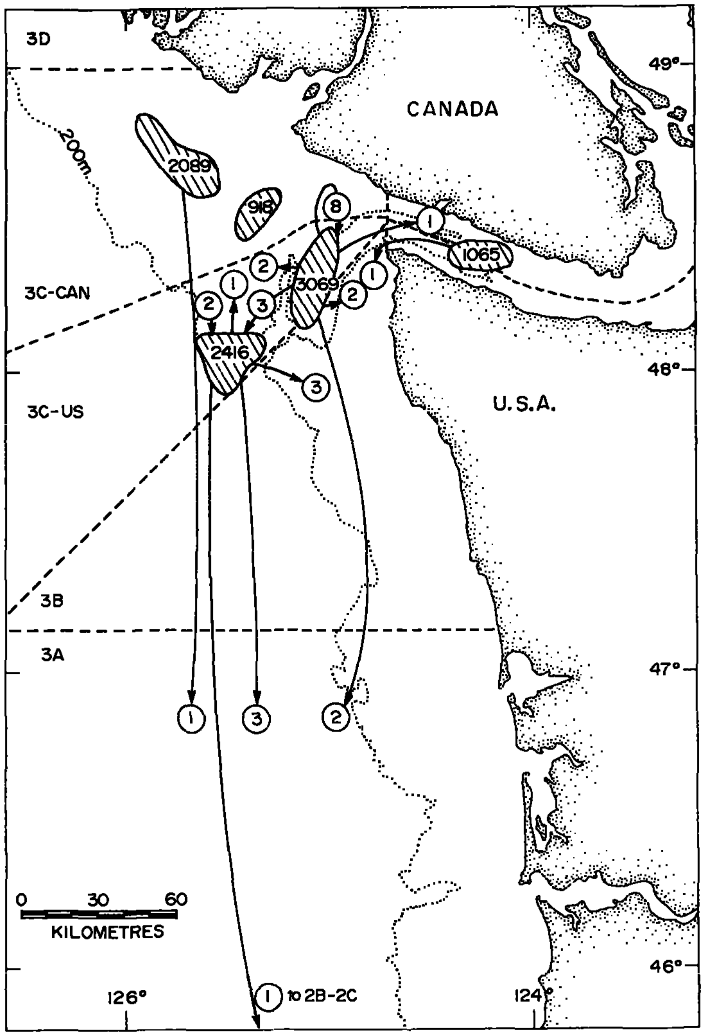

Figure 3
Number of releases (in hatched areas) and recoveries (in circles) of yellowtail rockfish, *Sebastes flavidus*, tagged off southern Vancouver Island and northern Washington (one specimen released in PSMFC area 3C-US was recovered in Areas 2B–2C to the south of the areas shown in this figure).

kan specimens (1.3%) was significantly higher ($P<0.05$) than in the Canadian study (0.26%), even without significant commercial fisheries in the area of release. The average length of all Alaskan-tagged fish was 37 cm (22–56 cm). The average length of recovered fish was 46 cm (45–50 cm). Based on the lengths, the recovered specimens were probably sexually mature when recovered, but probably immature when released.

Discussion

The recoveries of Alaskan specimens are congruent with earlier work, which indicated that immature yellowtail rockfish can make long distance movements (Mathews and Barker, 1983). The Canadian recoveries provide the first evidence that mature yellowtail rockfish can also move significantly longer distances than has been previously reported (Carlson and Haight, 1972; Pearcy, 1992).

The consistent tendency for individuals who travelled away from the release points to be caught farther south along the coast probably resulted from the bias in the distribution of the fishing effort. For the Alaskan and central B.C. releases, there were virtually no fisheries north or west of the release areas. It is surprising that none of the fish tagged in northern

Washington were recovered in Queen Charlotte Sound. However, landings of yellowtail rockfish in Queen Charlotte Sound were also low in the years during, and the first three years following, tagging (Table 4).

The yellowtail rockfish tagged in the Alaskan study were caught in waters shallower than 30 m and were predominantly immature. A southward, ontogenetic migration to the broader continental shelf off central B.C. is possible. This would parallel the movement of immature yellowtail rockfish from Puget Sound to the outer Washington coast (Mathews and Barker, 1983). However, many of these fish may simply move west towards the deeper water on the outer shelf but remain within southeastern Alaska. The limited commercial fishery in these outside waters prevents resolution of these alternatives, although they are not mutually exclusive.

Table 3

Minimum estimate of years at liberty for yellowtail rockfish, *Sebastes flavidus*, tag recoveries for those with reliable information on recovery date.

Time at liberty (yr)	Number of recoveries: Canadian	Alaskan
<1	8	0
1–2	5	0
2–3	7	0
3–4	5	0
4–5	1	0
5–6	2	2
6–7	2	0
7–8	2	3
8–9	2	0
9+	1	0
Total	35	5

Table 4

Landings (t) for 1980–89 and biomass estimates (t) for 1990 of yellowtail rockfish, *Sebastes flavidus*, by region (Stanley, 1991; Tagart, 1991).

Year of landings	SE Alaska	British Columbia[1]	Washington-Oregon-California[2]
1980		704	8,667
1981		426	9,181
1982	1	526	9,184
1983	2	447	9,498
1984	6	353	5,392
1985	5	941	3,449
1986	5	4,458	5,082
1987	8	4,168	5,212
1988	6	4,765	6,193
1989	4	4,298	4,516
1990 Exploitable biomass	unknown	30,000–45,000	20,000–40,000

[1] Northern Vancouver stock biomass partitioned 50% to Washington, 50% B.C.
[2] Does not include the bycatch in offshore fishing for Pacific hake, *Merluccius productus*.

We suggest that the low recovery rate for the Canadian study was caused by short-term post-tagging mortality arising from a combination of the greater depth of capture, the greater stress from trawl capture compared with hook-and-line, and the added handling during anaesthetization, decompression, and OTC injection. The dosage level of OTC may have also contributed to mortality, as studies on other species have shown increasing mortality with dosages greater than 25 mg/kg body weight (McFarlane and Beamish, 1987).

An alternative explanation for low recovery rates in the Canadian study is that the tagged fish were released into very large populations, well in excess of current estimates (Table 4). Thus, landings of 400–900 t in the early 1980's provided little chance for recovery. However, this same logic should then apply to the likelihood of recapturing Alaskan tags in the B.C. fishery at the same time. Since this recovery ratio was much higher, the Alaskan results support the contention of high initial mortality in the Canadian study.

The rate of recovery for Canadian tags was low at the outset and gradually declined over the ten years after release. The 95% confidence limits of the point estimate for the instantaneous rate of decline over the ten years (0.099–0.307) is consistent with the range of extinction rates (0.28–0.54) predicted by combining published estimates of instantaneous rates for natural mortality, 0.06–0.12 (Archibald et al., 1981; Tagart, 1991), tag loss for black rockfish, 0.13 (Lai and Culver, 1991), and fishing mortality for yellowtail rockfish off northern Washington, 0.09–0.29 (Tagart, 1991).

Despite the commercial importance of this species, the stock boundaries are poorly understood. Assessment biologists have resorted to selecting boundaries based on a combination of official statistical areas and on the distribution of major fishing grounds. The most recent assessments have assumed four stocks from groupings of International North Pacific

Fisheries Commission statistical areas: Charlotte/North Vancouver, South Vancouver, North Columbia, and Eureka/South Columbia (Stanley, 1991; Tagart, 1991) (Fig. 1).

This study does not provide information sufficient to alter the boundaries presently used in stock assessments. However, the clear demonstration of movement for immature and mature yellowtail rockfish should encourage assessment biologists to refine their understanding of stock relationships for this species. This understanding can then be applied to examination of the relative impacts of fishing mortality and potential movements among stock units.

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