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Evaluating Enhancement of Striped Bass in the Context of Potential Predation on Anadromous Salmonids in Coos Bay, Oregon

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Abstract.—We describe an approach for evaluating the predation on anadromous salmonids that could result from enhancement of striped bass *Morone saxatilis* in Coos Bay, Oregon. Predation by striped bass on juvenile salmonids has been documented there since 1930. To provide a basis for the decision about enhancement of striped bass in Coos Bay, we estimated the losses of anadromous salmonids in 1950 and 1960–1964. In this evaluation, we used information on striped bass in Coos Bay and collateral information about striped bass in other waters. Estimated numbers of juvenile salmonids consumed by striped bass in Coos Bay (April–June) ranged from more than 41,000 in 1950 to about 383,000 in 1963. Estimated losses of adult salmonids ranged from about 1,000 in 1950 to about 46,000 in 1963. This approach was useful in conveying the potential consequences of large-scale striped bass enhancement to decision makers and to the public. The evaluation also helped identify information needs that are now considered in managing the fishery and in evaluating impacts on salmonids.

Fisheries managers are often faced with decision making under uncertainty. Accurately predicting fish community responses to management alternatives is often difficult because data are limited and sometimes critical data cannot be obtained. In these situations an organized framework for decision making can prevent ill-advised trial-and-error management. Systems analysis has been proposed as a useful method to improve decision making in fish and wildlife management. A systems approach may simply be "nothing more than the application of good common sense as we think through a problem" (Grant 1986). Walters (1986) developed the concept of adaptive management as an organized framework for managing under uncertainty. The first step in adaptive management is the construction of predictive models to define the system and to identify key uncertainties (Milliman et al. 1987). We describe an approach used by the Oregon Department of Fish and Wildlife (ODFW) to identify potential consequences of a management action on fisheries in a coastal river.

Striped bass *Morone saxatilis* is not native to the west coast of North America. This species appeared in Coos Bay, Oregon, in 1914, about 45 years after its introduction in California. Striped bass later became well established in Coos Bay and by the 1940s, supported major commercial and sport fisheries (Morgan and Gerlach 1950). The sport fishery persisted through the 1950s and 1960s, attracting anglers from throughout Oregon and from other states. Because of dwindling striped bass populations and because of initiatives by sportfishing interest groups, commercial fishing for striped bass was prohibited by legislation in 1975. However, populations continued to decline into the 1980s (Temple and Mirati 1986). The cause of the population decline is unknown but may involve climatic instability and deteriorating water quality, two conditions thought to stress striped bass populations in the Chesapeake and San Francisco bays (Setzler-Hamilton et al. 1988).

In 1985 ODFW received a proposal, developed by a sportfishing organization, to enhance striped bass in Coos Bay. The issue was not new to ODFW biologists, and the proposal renewed the long-standing question whether enhancement is desirable. Biologists' primary concern with the proposal had to do with the feeding habits of striped bass. Striped bass eat a wide variety of invertebrates and fishes (Merriman 1941; Schaefer 1970; Manooch 1973; Rulifson and McKenna 1987) including salmonids (Shapovalov 1936; Morgan and Gerlach 1950; Thomas 1967; Deppert and Mense 1980). Coos Bay supports valuable populations of anadromous salmonids, particularly coho salmon *Oncorhynchus kisutch*, fall chinook salmon *O. tshawytscha*, and winter steelhead *O. mykiss*. Pre-

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Fisheries managers are often faced with decision making under uncertainty. Accurately predicting fish community responses to management alternatives is often difficult because data are limited and sometimes critical data cannot be obtained. In these situations an organized framework for decision making can prevent ill-advised trial-and-error management. Systems analysis has been proposed as a useful method to improve decision making in fish and wildlife management. A systems approach may simply be "nothing more than the application of good common sense as we think through a problem" (Grant 1986). Walters (1986) developed the concept of adaptive management as an organized framework for managing under uncertainty. The first step in adaptive management is the construction of predictive models to define the system and to identify key uncertainties (Milliman et al. 1987). We describe an approach used by the Oregon Department of Fish and Wildlife (ODFW) to identify potential consequences of a management action on fisheries in a coastal river.

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dation by striped bass on juvenile fall chinook salmon was of particular concern, because chinook salmon populations were rebuilding in Coos Bay; they had declined to near zero in the 1950s but then made a strong recovery. The decline of fall chinook salmon in Coos Bay coincided with large populations of striped bass and loss of spawning habitat, and the recovery coincided with reduced striped bass populations and improved habitat.

Because increased predation on juvenile salmonids could result from larger populations of striped bass, members of the public who were concerned about the salmon resource vocally opposed the enhancement proposal. Consequently, ODFW was faced with making a decision on a polarized subject with only limited data. Our approach, described in this paper, was to summarize available information and estimate potential losses of juvenile and adult salmonids at historical striped bass population levels. Loss estimates were based on the limited data available, on assumptions based on published information, and on intuition. Our intent was to put the striped bass enhancement levels proposed for Coos Bay in perspective relative to potential losses of juvenile salmon and steelhead.

Methods

Salmonid losses were expressed as losses of juveniles during their migration to the ocean and as losses of adults that would have contributed to sport or commercial fisheries or to natural or hatchery propagation.

Estimating losses of juvenile salmonids.—Losses of juvenile salmonids were estimated as the product of our estimate of predator-sized striped bass abundance and numbers of juvenile salmonids consumed per predator-sized striped bass. Data on striped bass abundance came from a tagging study conducted in 1950 (Morgan and Gerlach 1950) and from the commercial fishery records on catch per unit effort (CPUE; McGie and Mullen 1979). Data on striped bass food habits consisted of stomach analyses summarized in unpublished reports by the Oregon Game Commission (OGC) and Oregon Fish Commission (OFC). Confidence intervals for our striped bass abundance estimates could not be calculated because we had concurrent estimates of abundance and CPUE for 1950 only. Also, we could not calculate confidence limits on consumption of juvenile salmonids because the data used to determine average stomach contents were from pooled samples.

We estimated predator abundance in previous years to put the enhancement goals in perspective relative to historical levels of the predator population. We used Chapman's modification of the Peterson mark-and-recapture estimator (Ricker 1975) and tagging data published by Morgan and Gerlach (1950) to estimate predation abundance for 1950. We used CPUE data (average landings per licensed net) from the commercial fishery (McGie and Mullen 1979) to extrapolate abundance for 1960, 1962, 1963, and 1964 from the 1950 estimate.

We estimated consumption of juvenile salmonids by striped bass for April, May, and June, the only months when substantial numbers of striped bass and juvenile salmonids were found in Coos Bay. In estimating the consumption of juvenile salmonids per predator, we followed Bajkov (1935). Simply stated, daily consumption (C) was calculated as the product of the turnover coefficient (K) and the average stomach content (A), or $C = KA$. We estimated K and A as monthly averages. We estimated K as $24/n$, where n is the number of hours for complete gastric evacuation. We estimated n for each month, from the average water temperature reported for OGC and OFC and from the reported relationship of n to water temperature for perciform fishes (Windell 1978). To estimate A for each month, we divided the number of juvenile salmonids observed in striped bass stomachs by the number of striped bass stomachs examined that month. The number of salmonids consumed by striped bass per month was estimated by multiplying the daily consumption by the number of striped bass present and the number of days in the month. The number of juvenile salmonids consumed over the 3-month period was calculated as the sum of the monthly estimates.

Estimating losses of adult salmonids.—To estimate a range of losses of adult salmonids, we multiplied estimates of juvenile salmonids lost to predation by the lowest and highest juvenile-to-adult survival rates for salmonids present in Coos Bay (Nickelson 1986; ODFW 1986; A. McGie, ODFW, personal communication). Estimated survival rates in Oregon waters ranged from 2.4 to 12.0%, depending on species and stock.

Results and Discussion

Our estimate of striped bass abundance in 1950 was 17,382 (Table 1), based on a marked population of 189, a total catch of 3,384, and the recapture of 36 marked fish (Morgan and Gerlach 1950). We estimated the 95% confidence interval to be 12,650–23,820. Compared with our 1950 dation by striped bass on juvenile fall chinook salmon was of particular concern, because chinook salmon populations were rebuilding in Coos Bay; they had declined to near zero in the 1950s but then made a strong recovery. The decline of fall chinook salmon in Coos Bay coincided with large populations of striped bass and loss of spawning habitat, and the recovery coincided with reduced striped bass populations and improved habitat.

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TABLE 1.—Data used to estimate juvenile salmonid losses to striped bass predation in the Coos River. Data are presented by month for years in which stomach contents of commercially caught striped bass were examined.

Month	Estimated striped bass abundance	Stomachs sampled	Juvenile salmonids in stomachs sampled	Water temperature (°C)	Evacuation time (h)	Juvenile salmonids consumed per predator per day
			1950			
Apr	17,382	208	8	10	55	0.017
May	17,382	299	30	12	45	0.054
Jun	17,382	149	1	18	24	0.007
Apr–Jun		648	39			
			1960			
Apr	25,409	76	6	9	65	0.029
May	25,409	108	25	11	50	0.111
Jun	25,409	20	0	18	24	0.0
Apr–Jun		204	31			
			1962			
Apr	31,251	725	194	14	36	0.178
May	31,251	350	43	12	45	0.066
Jun	31,251	212	2	18	24	0.009
Apr–Jun		1,287	239			
			1963			
Apr	43,409	798	207	9	65	0.096
May	43,409	587	193	13	41	0.192
Jun	43,409	38	0	19	21	0.0
Apr–Jun		1,523	400			
			1964			
Apr	24,852	295	18	11	50	0.029
May	24,852	198	49	12	45	0.132
Jun	24,852	0	0	17	27	0.0
Apr–Jun		493	67			

estimate, abundance in the other years we examined increased as much as 2.5-fold (Table 1). Estimated numbers of juvenile salmonids consumed per predator per day ranged from 0.0 in June 1960, 1963, and 1964 to 0.19 in May 1963 (Table 1). Estimated median numbers of salmonids lost to predation by striped bass in April through June ranged from more than 41,000 in 1950 to about 383,000 in 1963 for juveniles and from about 1,000 in 1950 to about 46,000 in 1963 for adults (Table 2).

Estimates of striped bass abundance in 1950 (Morgan and Gerlach 1950) may be conservative because (1) sampling targeted spawning fish in the river and may not have included fish that spawned early or late or those that remained in the bay, and (2) the fishery was highly selective and did not representatively sample fish of ages 1–3 or those older than age 10. Estimates of striped bass abundance in 1960 and 1962–1964 were made with the assumption that average catch per licensed net is an appropriate index of relative abundance among years. However, because mean CPUE often underestimates differences in abundance (Bannerot and Austin 1983), differences in abundance of striped bass among the years examined may have been greater than estimated.

Estimates of numbers of juvenile salmonids eaten per predator per day relied on several assumptions (Table 3) and may be conservative. Stomach contents from striped bass caught in the commercial gill-net fishery may have reflected smaller numbers of salmonids than were consumed, because fish continue to digest prey and sometimes regurgitate it while they are entangled in nets and struggle to get free (Windell and Bowen 1978). Also, losses may have been underestimated because the striped bass samples used were confined to fish caught in April, May, and June in the river proper; salmonids have been observed in stomachs sampled from fish collected by recreational anglers in February and March and from the bay downriver from the commercial fishery (Temple and Mirati 1986). Numbers of juvenile salmonids

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TABLE 2.—Estimates of juvenile salmonid losses to striped bass predation and estimates of the resulting adult salmonid losses in the Coos River. Data are presented by month for years in which stomach contents of commercially caught fish were examined. Juvenile-to-adult survival rates (S) represent the low and high values reported for salmonid species and stocks found in the Coos River.

Month	Estimates of median number of juvenile salmonids consumed	Estimates of median number of adult salmonids lost	
		S = 2.4%	S = 12.0%
	1950		
Apr	8,865	213	1,064
May	29,097	698	3,492
Jun	3,650	88	438
Apr–Jun	41,612	999	4,994
	1960		
Apr	22,106	530	2,653
May	87,432	2,098	10,492
Jun	0	0	0
Apr–Jun	109,538	2,628	13,145
	1962		
Apr	166,880	4,005	20,026
May	63,940	1,535	7,673
un	8,438	203	1,013
pr–Jun	239,258	5,743	28,712
	1963		
pr	125,018	3,000	15,002
ay	258,370	2,201	31,004
n	0	0	0
pr–Jun	383,388	9,201	46,006
	1964		
r	21,621	519	2,595
y	101,694	2,441	12,203
n	0	0	0
r–Jun	123,315	2,960	14,798

Coos Bay in the 1980s were at least comparable numbers of those present in the 1960s (Temple d Mirati 1986); however, we have no comparns for abundances of alternative prey. Striped s may be selecting juvenile salmonids at dif-nt rates now than in the 1960s if abundances lterntive prey have changed significantly.

stimates of adult salmonid losses resulting from lation on juveniles are uncertain; these esties may be affected by the relative abundance e species and stocks of salmonids considered, by the absolute abundance of juvenile salmo-and predators. The significance of predation vary greatly with changes in numbers of pred- and prey (Larkin 1979). Also, because of actions among predators, changes in predation by one species may be compensated by corresponding changes in predation by another (Campbell 1979; Larkin 1979). How changes in striped bass predation affect survival of juvenile salmonids to adulthood may be confounded by how predation by the community of predators responds to changes in the population of one of its members. Also, net effects of predation in general on survival of juvenile salmonids to adulthood may be mitigated or amplified by density-dependent factors in the ocean.

When ODFW decided to evaluate the effects of striped bass enhancement on production of anadromous salmonids, it already recognized that striped bass would consume juvenile salmonds if given the opportunity (Shapovalov 1936; Morgan and Gerlach 1950; Thomas 1967). The questions were, how many juvenile salmonids would be lost to predation if the striped bass population were increased? and how would those losses affect the immediate and future production of anadromous salmonids? An important management objective was to develop a striped bass enhancement scheme that would not foreclose or reduce future enhancement options for salmonids.

We could not estimate the proportion of juvenile salmonids lost to striped bass predation during the months and years we examined because we had no data on numbers of juveniles migrating from or adults returning to the system. In fact, at the completion of our analysis, ODFW still had no program to collect this information. Lack of information on the proportion of juvenile salmonid production lost to predation is the reason we translated juvenile salmonid losses to estimates of adult salmonids lost. Decision makers felt that the significance of numbers of adult salmonids lost because of predation on juveniles could be judged independent of the relative size of the run.

The scientific merits of many of the assumptions critical to this analysis have been and will continue to be questioned. Despite the uncertainty in the salmonid loss estimates, these estimates were sufficient to make people on both sides of the issue consider the potential consequences of proposed actions and alternatives. Though possibly not fully supportable, our estimates of adult salmonid losses of up to 46,000 fish (Table 2) were especially helpful in conveying potential consequences of large-scale striped bass enhancement to the public and to decision makers of the Oregon Fish and Wildlife Commission. The commissioners ultimately required development of a management plan that considered striped bass enhancement in the con-

TABLE 3.—A

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TABLE 3.—Assumptions on which estimates of juvenile and adult salmonid losses were based.

Assumption	Is the assumption a violation of actuality? How?	Results
Striped bass feed continuously, night and day	Yes. Feeding activity is greatest during daylight	Daytime samples overestimate nighttime consumption. However, because catches in the commercial fishery come from day and night net-sets, the stomach samples represent both feeding patterns
Prey items in striped bass stomachs are identifiable and represent striped bass diet at the time and place of sampling	Yes. Digestion before and after death of predator reduces identifiability of prey. Also, when striped bass are caught in gill nets they may regurgitate their stomach contents	Numbers of salmonids consumed may be underestimated
Estimated numbers of striped bass available to the commercial fishery reflect numbers of striped bass present in areas where fish were caught for stomach samples	Yes. Basis for estimating the number of striped bass that potentially use the area is reasonable. However, not all adult striped bass are present during the entire April–June period	Numbers of salmonids consumed may be overestimated. Striped bass population estimates are based on fish available to the commercial fishery; stomach samples used in consumption modeling are taken from these fish
Population size is proportional to catch per licensed net	Yes. Catch per licensed net is not an absolute measure of catch per unit of effort; however, it is the best available measure of population size	Striped bass population may be underestimated
Striped bass stomach samples accurately represent prey consumption by feeding and nonfeeding (spawning) striped bass	No. Consumption rates are expressed as total salmonids in the stomachs divided by total number of striped bass stomachs sampled, thus no bias occurs	Overall rates of consumption of salmonids by striped bass are valid, regardless of mix of feeding and nonfeeding striped bass sampled
Digestion by striped bass occurs within the range of rates determined for centrarchids and percids (Mann 1978)	Unknown. However, a median value in a range from low to high rates is used	Consumption rates may be overestimated or underestimated, depending on direction of error in digestion rates
Consumption of salmonids by striped bass is underestimated, but most predation occurs within the times and areas sampled	Yes. There is evidence that striped bass running upriver in January, February, and March consume salmonids, and that striped bass in midbay consume salmonids	Numbers of salmonids consumed may be underestimated. However, most predation occurs within the times and areas sampled
Salmonid survival to adulthood, calculated from juvenile salmonid losses to predation, falls within the range reported for Oregon waters—that is, survival does not vary with numbers of juvenile salmonids or predators present in Coos Bay or the ocean	Yes. Survival in rivers and the ocean may vary, depending on numbers of juvenile salmonids or predators present	Numbers of juvenile salmonids that do not survive to adulthood because of predation may be underestimated or overestimated, depending on direction of changes in juvenile salmonid and predator numbers

text of all other Coos Bay fisheries. That plan authorized enhancement of the striped bass population to a level of 20,000 adults, which was viewed as the minimum number required for an acceptable sport fishery and for effective assessment of impacts on salmonids. Our analysis allowed the commissioners to reach their decision on striped bass enhancement with the knowledge of its potential consequence on the salmonid population—that is, a reduction of up to 15,000 adult salmonids. The plan also directed that the consumption of salmonids by striped bass be closely monitored and evaluated.

Although we can only conjecture whether the same policy would have emerged in the absence of our analysis, both sides perceived the process as a good-faith effort by ODFW to use available data to address some of the major questions. Our analysis confirmed that large striped bass populations may limit enhancement options for anadromous salmonids, and it identified information (e.g., estimates of present juvenile salmonid and striped bass production potential) needed to develop striped bass management strategies in the Coos Bay management plan. These information needs prompted a research effort that accompanied the authorization to enhance the striped bass population to 20,000 adults. Consequently, we be-

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Striped bass feed continuously, night and day	Yes. Feeding activity is greater during daylight	Daytime samples overestimate nighttime consumption. However, because catches in the commercial fishery come from day and night net-sets, the stomach samples represent both feeding patterns
Prey items in striped bass stomachs are identifiable and represent striped bass diet at the time and place of sampling	Yes. Digestion before and after death of predator reduces identifiability of prey. Also, when striped bass are caught in gill nets they may regurgitate their stomach contents	Numbers of salmonids consumed may be underestimated
Estimated numbers of striped bass available to the commercial fishery reflect numbers of striped bass present in areas where fish were caught for stomach samples	Yes. Basis for estimating the number of striped bass that potentially use the area is reasonable. However, not all adult striped bass are present during the entire April–June period	Numbers of salmonids consumed may be overestimated. Striped bass population estimates are based on fish available to the commercial fishery; stomach samples used in consumption modeling are taken from these fish
Population size is proportional to catch per licensed net	Yes. Catch per licensed net is not an absolute measure of catch per unit of effort; however, it is the best available measure of population size	Striped bass population may be underestimated
Striped bass stomach samples accurately represent prey consumption by feeding and nonfeeding (spawning) striped bass	No. Consumption rates are expressed as total salmonids in the stomachs divided by total number of striped bass stomachs sampled; thus no bias occurs	Overall rates of consumption of salmonids by striped bass are valid, regardless of mix of feeding and nonfeeding striped bass sampled
Digestion by striped bass occurs within the range of rates determined for centrarchids and percids (Rice 1978)	Unknown. However, a median value in a range from low to high rates is used	Consumption rates may be overestimated or underestimated, depending on direction of error in digestion rates
Consumption of salmonids by striped bass is underestimated, but most predation occurs within the times and areas sampled	Yes. There is evidence that striped bass feeding upriver in January, February, and March consume salmonids, and that striped bass in the bay consume salmonids	Numbers of salmonids consumed may be underestimated. However, most predation occurs within the times and areas sampled
Salmonid survival to adulthood, calculated from juvenile salmonid losses to predation, falls within the range reported for Oregon waters—that is, survival does not vary with numbers of juvenile salmonids or predators present in Coos Bay or the ocean	Yes. Survival in rivers and the ocean may vary, depending on numbers of juvenile salmonids or predators present	Numbers of juvenile salmonids that do not survive to adulthood because of predation may be underestimated or overestimated, depending on direction of changes in juvenile salmonid and predator numbers

tent of all other Coos Bay fisheries. That plan authorized enhancement of the striped bass population to a level of 20,000 adults, which was viewed as the minimum number required for an acceptable sport fishery and for effective assessment of impacts on salmonids. Our analysis allowed the commissioners to reach their decision on striped bass enhancement with the knowledge of its potential consequence on the salmonid population—that is, a reduction of up to 15,000 adult salmonids. The plan also directed that the consumption of salmonids by striped bass be closely monitored and evaluated.

Although we can only conjecture whether the same policy would have emerged in the absence of our analysis, both sides perceived the process as a good-faith effort by ODFW to use available data to address some of the major questions. Our analysis confirmed that large striped bass populations may limit enhancement options for anadromous salmonids, and it identified information (e.g., estimates of present juvenile salmonid and striped bass production potential) needed to develop striped bass management strategies in the Coos Bay management plan. These information needs prompted a research effort that accompanied the authorization to enhance the striped bass population to 20,000 adults. Consequently, we believe that the effort to estimate salmonid losses from striped bass predation was useful in addressing this particular fisheries management issue.

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