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ESCAPED SALMON IN THE INNER SEAS, SOUTHERN CHILE: FACING ECOLOGICAL AND SOCIAL CONFLICTS

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Abstract. During heavy storms in 1994–1995, salmon farms in southern Chile lost several million fish from the most commonly farmed species, rainbow trout (*Oncorhynchus mykiss*), coho salmon *(Oncorhynchus kisutch*), and Atlantic salmon *(Salmo salar*). To determine the abundance and distribution of such exotic salmon populations in the wild and their effect on native organisms, we conducted experimental fishing, in six locations in the salmon farming regions (41°–46° S) in the inner seas of Chiloé (X Region) and Aysen (XI Region), between November 1995 and December 1996. At the same time, we collected information from salmon farms and insurance companies about escaped individuals. During the experimental fishing we captured 2602 coho salmon, 984 trout, and 271 Atlantic salmon. Captures of the three species declined through the duration of the study; thus in November 1996 we captured $<$10% of initial catches. Population projections based on three possible mortality rates (0.4, 0.8, and 1.2) predicted the disappearance of salmon by year 2000, and the highest mortality rate was the best predictor of the observed available biomass in 1996. Thus, artisanal fishing may control escaped salmon. Of the three species, coho salmon had the best chances of becoming established in the remote XI Region where the artisanal fishing pressure was less intense.

The three salmon species showed feeding similarities, since each kept feeding on pellets beneath the farms, particularly Atlantic salmon, while coho salmon showed greater preference for schooling fish, and rainbow trout fed more often on crustaceans. Thus, the three species, particularly coho salmon, could compete with native southern hake and mackerel. As a management approach to avoid salmon colonization and naturalization in southern Chile, local artisanal fishing should be encouraged because it is probably the most efficient way to remove escaped individuals and reduce the chance of populations becoming self-sustaining.

Key words: artisanal fishing; escaped salmon; exotic species introduction; salmon farming; salmon feeding in the wild; salmon fishery; social conflict; southern Chile inner seas; wild salmon.

INTRODUCTION

Invasions by exotic species are presently considered as one of the major global threats to ecosystems from both ecological and economic perspectives (Lodge 1993, Vitousek 1994). Exotic fish introductions are common and they usually result from (1) introductions for sports fishing (Davidson and Hutchinson 1938), (2) accidental escapes of farmed fish, and (3) aquarium releases. This paper deals with some of the side effects of aquaculture, more specifically with salmon farming, in southern Chile and the potential threats due to the introduction of exotic species.

Salmon farming began in Chile ~1980 and since then it has experienced exponential growth from $<$10 000 Mg in 1988, to a production of ~200 thousand Mg in 1999. In Chile the most commonly farmed species are rainbow trout (*Oncorhynchus mykiss),* coho salmon (*Oncorhynchus kisutch),* Atlantic salmon (*Salmo salar*), and to a lesser extent, chinook salmon (*Oncorhynchus tshawytscha*).

Salmon are not native to the Southern Hemisphere. They have been introduced for sport fishing or aquaculture purposes into New Zealand and South America (Elton 1958, Joiner 1980). The first introductions in Chile can be traced to the early 1900s when brown trout (*Salmo trutta fario*) and rainbow trout (*Oncorhynchus mykiss*) were successfully introduced to lentic and lotic environments around the country for sport fishing purposes. At present, the largest populations are located in the south of the country (beyond 36° S) where an important sport fishery takes place. At the time of the initial releases there were no studies on the potential effect of these introductions on the native fauna.

Most salmon are anadromous, starting their life cycle in freshwater and migrating downstream through estuaries into the marine environments. In Chilean salmon farming, smolt production usually takes place in the

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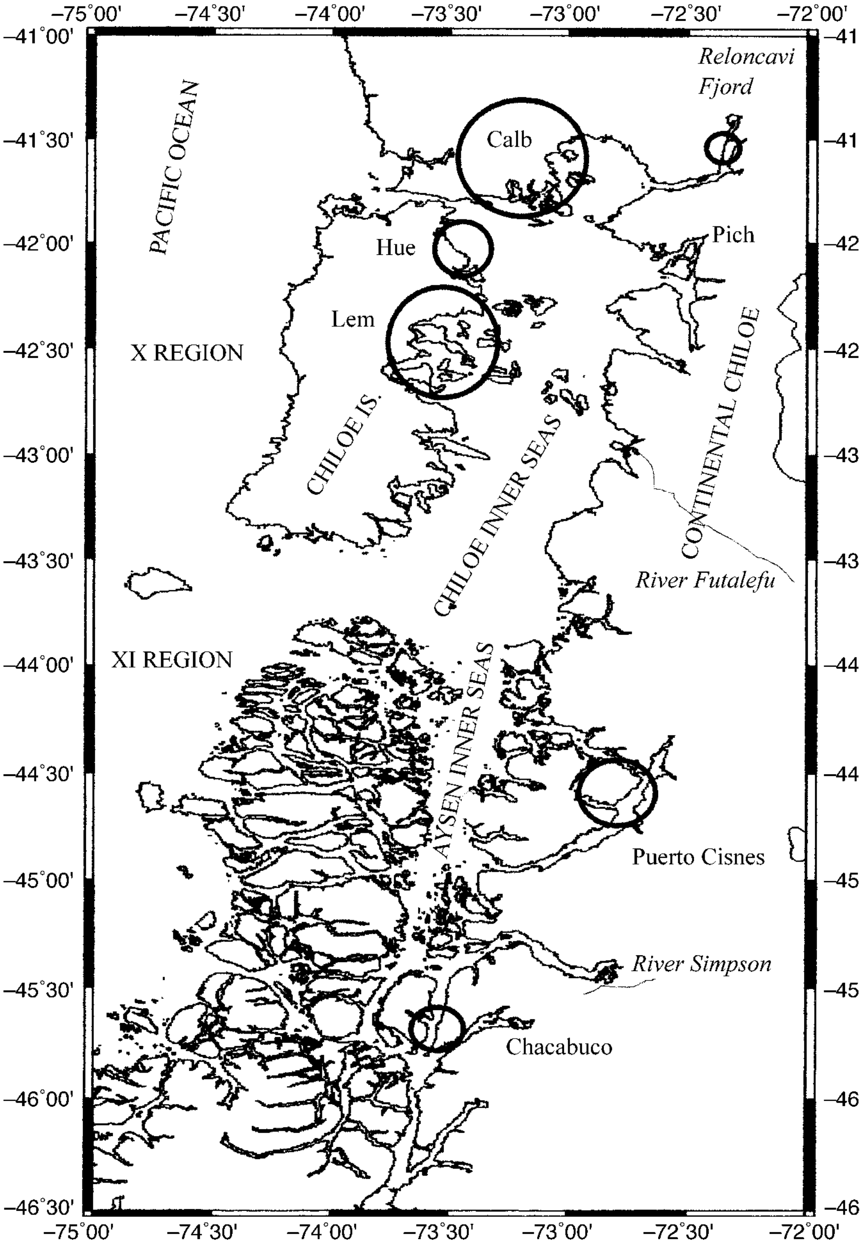

FIG. 1. Salmon farming regions in southern Chile. The circles indicate the main salmon farming areas, and the size of each circle represents the approximate extension and total biomass being farmed by 1996. The experimental fishing sites are inside the circles (Calbuco, Hueihue, Lemuy, Puerto Cisnes, and Chacabuco) with the exception of the control site Pichicolo, located in a more remote area of mainland Chiloé that did not have salmon farming at the time. Reloncavi Fjord as a salmon farming area was not included in this study.

largest oligotrophic lakes, while commercial grow-out occurs in the protected inner seas and fjords of Chiloé (X Region) and Aysen (XI Region), the two salmon-producing regions (Fig. 1). Most salmon grow-out is in floating pens where the salmon are tended and fed. Every year, especially during winter storms (June–July), some salmon accidentally escape when containment fails. During some of the heaviest storms in 1994 and 1995, according to local reports, $>4 \times 10^6$ salmon (ranging from juvenile to adult) escaped from their containment within the two salmon regions.

Farmed vs. free-living salmon

Since 1994, escaped salmon have become an important catch in the nets of artisanal fishermen, who argue that these species are damaging their regular coastal fishery and have requested legal permission to establish a salmon fishery. Thus, an important long-term management issue is clarifying the ability of these fish to establish wild populations after successful reproduction.

A very significant problem caused by the release of large salmon populations in the wild is the potential impact on the native fauna, habitats, and ecosystemic services. The impact of introduced salmon has been well documented in freshwaters of New Zealand (Elton 1958, McDowell 1978). However, their effect as exotic species in the ocean is less known in the Southern Hemisphere. In Chile, the introduction of these exotic species has only recently been considered a potential threat to preservation of biodiversity. Salmon introduction attempts, before 1970, were based on the possibility of open ‘‘empty niches’’ for salmon species in aquatic ecosystems of southern Chile, and most trout introductions were promoted and sponsored by the Chilean government through agreement with U.S. fisheries institutions (Davidson and Hutchinson 1938, Soto 1997). If any salmon species succeed in establishing wild populations, management decisions will entail whether to leave them on their own or to regulate their populations.

As a general hypothesis, we would expect that the distribution and abundance of salmon species would be related to the distribution of salmon farms and total aquaculture production, more than to other factors such as distribution of suitable habitats (e.g., for reproduction). Such a hypothesis is based on the potentially large number of recent escapees and on the failure of previous introduction attempts to establish large acclimated populations of other salmon species (Joiner 1980). Thus, our study had the following objectives: (1) to ascertain which salmon species are presently free living, their relative abundance, and where are they distributed in the Chiloé and Aysen inner waters (Fig. 1), (2) to project population and biomass growth from escapees to evaluate the feasibility of establishment as wild salmon populations and the development of a potential artisanal salmon fishery, and (3) to determine potential effects of salmon on native fauna, particularly through trophic interactions. With regard to (1), we recognize the distinction between ‘‘wild salmon,’’ salmon born in the wild, and ‘‘free-living salmon,’’ fish of unknown origin that may have been produced under farmed conditions but are swimming free for a length of time (>6 mo). In this work, however, we make no attempt to differentiate these two groups and we refer to ‘‘free-living salmon’’ or ‘‘captured salmon’’ rather than ‘‘wild salmon.’’

METHODS

Experimental fishing

To achieve these objectives, we started a fishing program in six localities of the Chilean inner ocean and fjords between 41° S and 46° S, covering a latitudinal transect of almost 1000 km. The sampling sites were located according to their proximity to salmon farms, attempting to cover the widest possible range where fishermen fish the salmon (Fig. 1).

In the X Region, the selected localities were Calbuco, Hueihue, Lemuy, and Pichicolo (Fig. 1). Calbuco and Lemuy were the sites nearest to areas with the largest number of farms and salmon floating pens, while Hueihue is a site with little farming activity. Pichicolo, at the time of this study, was the most remote site from both human activities and salmon farming (Fig. 1). Therefore, it was considered a control or reference site. It was impossible to find other accessible control sites, since most protected coves and fjords all over the Region are already occupied by salmon farming, and those remaining are not easily accessible by land or water. In the XI Region (Fig. 1) we selected Puerto Chacabuco, the area with the most farming activity in the region, and Puerto Cisnes, a more remote area, with smaller salmon production.

On each site we established a sampling approach similar to the typical fishing mode of local coastal artisanal fishermen. This was achieved by using two small boats (6–10 m long), each operating a set of three gill nets (mesh sizes of 7.6, 12, and 15.8 cm respectively). Those mesh sizes were chosen because they allowed capturing a wider spectrum of fish sizes than fishermen, who usually do not use the 7.6-cm net. Once deployed, each net formed a wall 75 m long and 3 m high, positioned perpendicular to the shoreline. Simultaneous 3–4 d fishing periods took place at each locality every 30 or 40 d, resulting in 12 sampling events along a 13-month span starting in November 1995 and ending in December 1996. This sampling effort was confirmed as similar and comparable among all sites. We also estimated total artisanal catches during that period by expanding our results to those obtained by the approximate total number of fishermen, boats, and days fished. Estimated total artisanal catch for 1995 was calculated based only on our experimental catches for November and December, while total catch for 1996 was based on the mean among sites for 10 months.

After deployment, the nets were checked periodically, and the fish were removed from the nets every 4–6 h. All fish collected, including salmon and native species, were individually identified, measured, weighed, and sexed. Additionally, stomachs were removed and preserved by injecting 10% formaldehyde solution. Stomach content analysis of salmon and native species allowed comparison of diet overlap and also permitted the elaboration of potential food webs. Scales were collected from salmon species for age and growth determination. When the fish caught were too numerous, we randomly extracted a representative subsample of 15–20 individuals of each species, to which we applied the treatments and procedures described above.

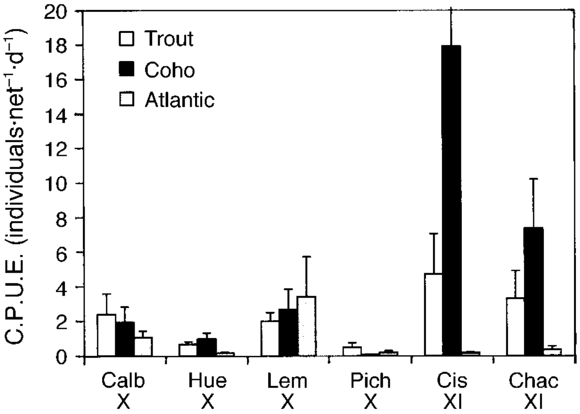

FIG. 2. Mean index for salmon abundance over the whole fishing period, expressed as number of fish caught per net per day (C.P.U.E.) on each site: Calbuco (Calb), Hueihue (Hue), Lemuy (Lem), Pichicolo (Pich), Puerto Cisnes (Cis), and Chacabuco (Chac). Error bars represent one standard error, $N = 12$ or 13. Regions (X or XI) are indicated under the site name.

Population projections from escaped salmon

In order to establish the actual state of the populations in the wild, and to evaluate potential natural recruitment relative to escapees, it was necessary to estimate the latter. Thus, our initial null hypothesis was that no natural recruitment was effectively taking place in the wild. We therefore assumed that all individuals joining the free-living salmon populations were escapees from the farms. To test this assumption we first gathered information on releases from salmon farming and insurance companies. The latter keep accurate records of the claims and causes of salmon losses from farms. We devised a simple questionnaire asking for the numbers of fish lost by species, age, mean mass, and localities and dates of accidental escapes. We pooled the data by locality where several independent farms could be included, and we extrapolated the development of populations in time, using the ''recruitment'' at each age class as estimated from the questionnaires about escapees. This resulted in a population that was not age structured, because the magnitude and characteristics of fish escapes were rather random in size and/or age, although most individuals that escaped from one particular pen or group of pens were usually of the same age (i.e., production year). Thus, we used a model with a general decay rate (Z) of escaped populations in the inner seas, which included mortality due to fishing, natural mortality, and reproductive attrition (adults entering freshwater to spawn) if there was any. To do so, we made population projections using different mortality rates, starting with a natural one (not including attrition) reported by McGurk (1996), $Z = 0.40$, and also used larger values of 0.80 and 1.2 that could have included attrition and fishing. Later, we contrasted the predicted survival numbers with catches at the end of the experimental fishing in December 1996 and later. Simulated projections were based on Rickers (1975) approach to temporal decrease at a specific age due to mortality.

We also included new escapees of older ages, which added to the corresponding projected cohort sizes in a ''years vs. age'' matrix. This assumed that those individuals had the same phenotypic length and mass as those already included. The projections were extended until the age of reproduction and death occurred for each species of salmon under analysis, according to known life-span characteristics obtained from the literature (Groot and Margolis 1991). Simulated projections for biomass used mean mass for each age class, and we assumed that there have been no further escapes after 1995 and that no significant reproduction has taken place in the wild, i.e., that no recruitment to the free-living population had occurred recently.

The information on size, mass, and age structure of ''survivors'' was obtained from the individuals caught in the experimental fishing. Age structure was obtained from scale readings and cross-checked with farmed individuals of known age. At least two scales in good condition were analyzed from each fish. In total, we used scales from 300 trout, 337 coho salmon, and 106 Atlantic salmon. We also read scales from ≥150 farmed individuals of known age for each of the three species, in order to compare growth rates between them and the captured salmon. We used length–mass relationships to calculate projected biomass. During the experimental fishing we measured and weighed a total of 504 trout, 846 coho salmon, and 245 Atlantic salmon.

Data analysis

To compare the relative abundance of fish within and among sites and through time, we calculated the number of fish or biomass captured per unit effort (C.P.U.E.) as an index of abundance. A unit of effort consisted of the full standardized set of gill nets deployed at each site to capture fish; the number of fish captured was also standardized to account for the number of hours the nets were deployed. Thus, the C.P.U.E. was expressed as ''number of fish caught per net per day.''

We used t tests to compare growth rates between farmed and free-living individuals. When needed, we used geometrical transformations or log-transformed data to meet variance homogeneity requirements.

RESULTS

Distribution and abundance of free-living salmon in the Chiloé and Aysen areas

During the 13-mo sampling period we captured five salmon species. Coho salmon was the most abundant (2602 individuals), followed by rainbow trout (984 individuals), and Atlantic salmon (271 individuals). These species were regularly caught, while there were very few, sporadic catches of chinook salmon and brown trout.

TABLE 1. Mean capture per unit effort (kg·net^{-1}·d^{-1}) of salmon (all species together) and native species (incidental catch) at the six sampling sites in southern Chile.

	Total salmon		Native species		
Locality	Mean	1 SE	Mean	1 SE	*n*
Calbuco	9.8	4.5	3.6	2.5	12
Hueihue	3.2	1.1	1.9	0.3	12
Lemuy	16.0	9.0	1.8	0.4	11
Pichicolo	1.8	0.8	6.2	1.5	11
Cisnes	54.7	18.4	3.8	1.2	12
Chacabuco	19.1	6.6	3.2	1.1	12

Note: The *n* is the number of independent sampling periods per site.

Captures per unit effort and total captures were much higher in the XI Region than in the X Region, and the relative proportions of each species differed between the two regions. While Atlantic salmon was abundant in the X Region (especially in Lemuy and Calbuco), this species was rare in the XI Region (Fig. 2). Coho salmon was most abundant in the XI Region, accounting for >80% of the total experimental catch (Table 1, Fig. 2). Also, in all the sites except Pichicolo (where no farms were operating), salmon were strongly dominant over native fish fauna. In the X Region, mean C.P.U.E., expressed in biomass, ranged from 1.75 to 9.8 kg salmon·net^{-1}·day^{-1}, while in the XI Region the C.P.U.E. ranged from 19.1 to 54.78 kg salmon·net^{-1}·day^{-1}, with Puerto Cisnes as the most productive site (Table 1, Fig. 2). Pichicolo (the site without salmon farming) showed the smallest captures of all three salmon species, but the largest incidental catch of native fish species (Table 1, Fig. 3).

The highest salmon catches in the X Region sites took place during November and December 1995, while in the XI Region the highest captures were between November 1995 and May 1996. Later, salmon catches declined steadily at all sites, particularly in the X Region (Fig. 3), and catches were very reduced by the end of the study period (December 1996).

Total estimated artisanal catch in the two regions for the 1996 period was 1387 Mg, while the value for 1995

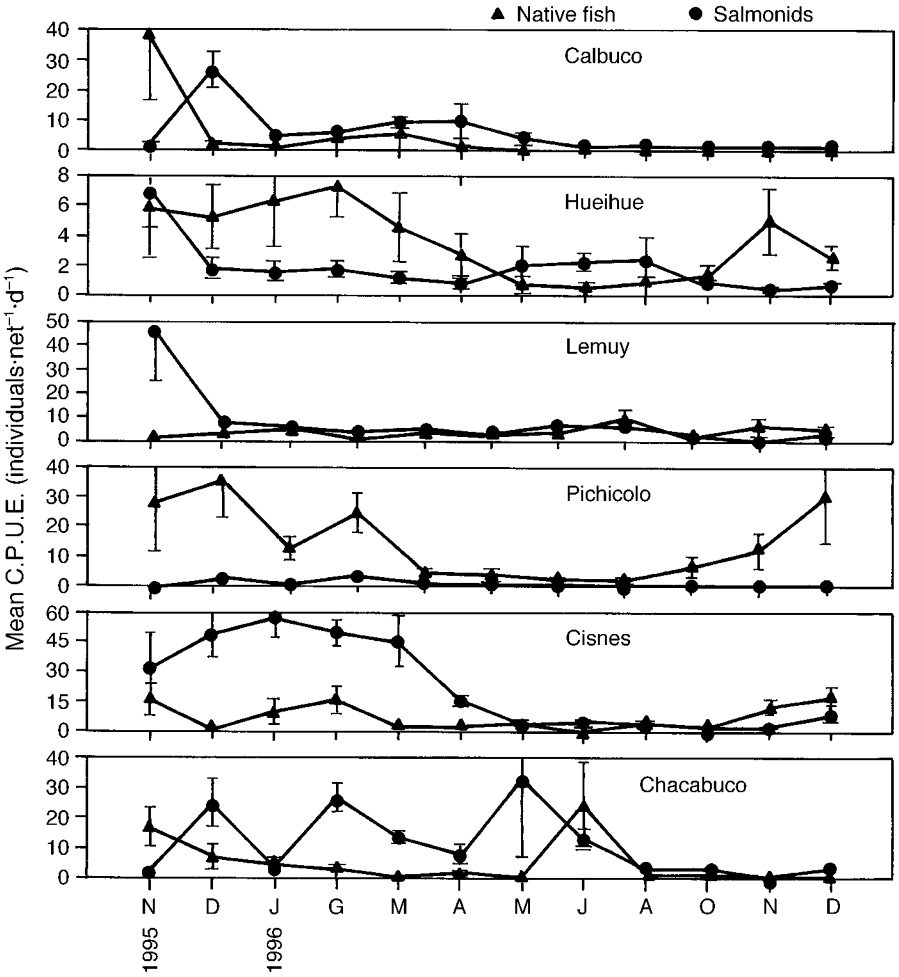

FIG. 3. Mean number of fish caught per net per day (C.P.U.E.), for each sampling date on each site. Total salmon species are the solid circles, and total native fish are the solid triangles. Note that scales are different for some sites.

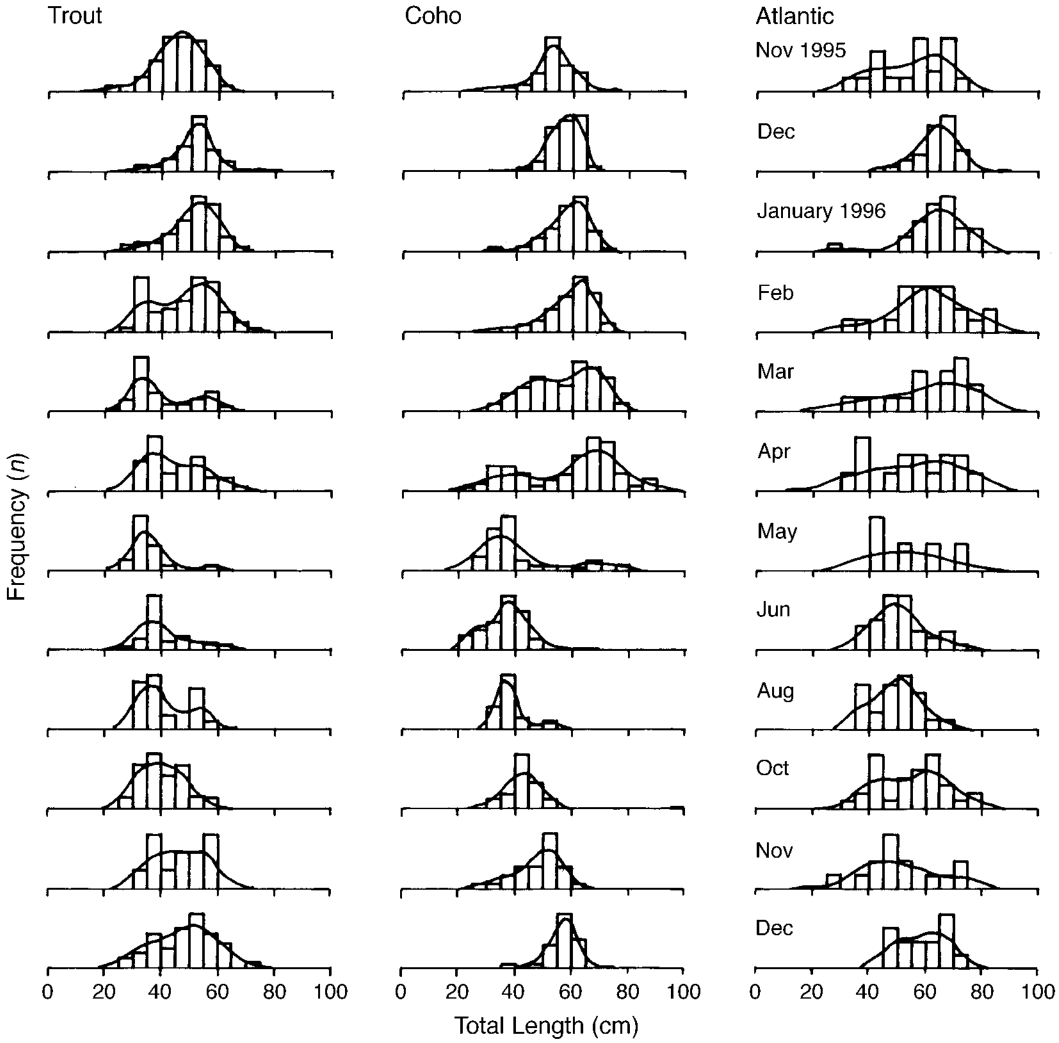

FIG. 4. Size (total length) frequency distribution of each species for each sampling date. All sites are pooled.

was 2366 Mg. The latter is less certain as it is based on the projection from only two months of experimental fishing.

Size–age distribution and modal displacement through time

The size of salmon captured ranged between 21 and 86 cm total length. While the representation of the smaller size classes was probably underestimated due to gill net selectivity, the larger size classes should have been well represented, as the nets could capture even larger sizes. Rainbow trout were the smallest fish, while Atlantic salmon were the largest, with several individuals >80 cm in length (Fig. 4).

Trout, coho salmon, and Atlantic salmon showed three to four modal size classes with a clear displacement in time, suggesting body growth from November 1995 to May 1996. After May, the largest sizes disappeared from the population sampled, and smaller individuals dominated captures (Fig. 4). Younger individuals, which apparently grew from May to December 1996 (Fig. 4), included two age classes or cohorts: the largest sizes for the 1+ class and the full size distribution of the 2+ class.

The largest proportion of the trout captured corresponded to individuals in the 1+ and 2+ age classes, while >40% of coho salmon were in the 2+ and 3+ age classes, and >50% of the Atlantic salmon were in the 3+ and older age classes (Fig. 5). The sizes reported here for the fish captured were well within the size and age range of farmed salmon; also, their age structure corresponded well with that projected from individuals that had escaped from farms on previous years.

Growth rates did not differ between farmed salmon and free-living individuals during the first year of age ($P > 0.05$ for all the comparisons on log-transformed data, all three species). Trout growth rates during the second year, in Calbuco, Puerto Cisnes, and Chacabuco

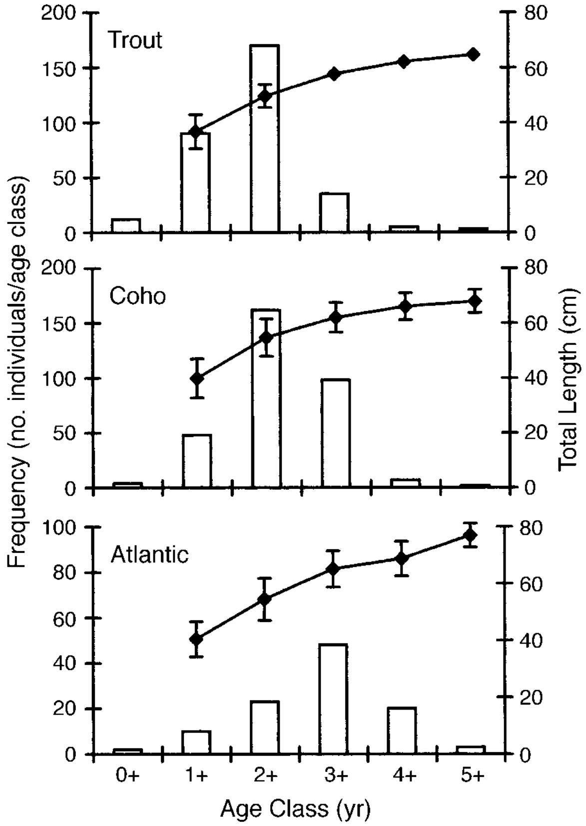

FIG. 5. Age frequency distribution (bars) and mean size (line; ± 1 SE), for all captured individuals of each species.

were significantly lower in free-living individuals than in farmed trout (t test, $P < 0.01$, $P < 0.001$, and $P < 0.01$, respectively) (Fig. 6). Growth rates of captured Atlantic salmon were significantly smaller than those observed in farmed fish ($P < 0.001$ and $P < 0.01$ respectively), particularly during the 2+ year. Conversely, coho salmon did not show significant differences in growth rates for the 2+ year, between farmed and captured individuals (Fig. 6). During the third year of age no significant differences were detected for any of the three species, possibly due to the sparse number of individuals to compare.

Escapees number and population simulation

From the answers to questionnaires distributed to salmon farms and from information provided by insurance companies, we estimated that between 1994 and 1996 $>4 \times 10^6$ salmon escaped from their pens, most of them corresponding to the 1+ age class or older, and with a mass of >1 kg. This amount is likely underestimated, since we did not get enough information on escapees from the XI Region. There, <30% of the insurance companies approached provided reliable data. Thus, 3.4×10^6 salmon reportedly escaped from the pens in the X Region, while the reported numbers in the XI Region were less than one million. Also, the largest number of salmon escaped during 1994 in the X Region, while in the XI Region the largest escapes took place in 1995. Thus, the simulated population projections we made were mostly based on the data for the four sites in the X Region. Escaped salmon numbers per region are proportional to biomass and production per region.

Table 2 shows the approximate number of individuals of each species and age class recruiting into the free-living population every year. The table also shows that coho salmon and Atlantic salmon were the largest contributors to the free-living salmon population.

Using these numbers we simulated three curves for available biomass in time, each with a different mortality or decay rate (Fig. 7). Estimated total trout biomass remaining by 1999 should have been 57 Mg and 10 Mg with $Z = 0.80$ and 1.2 respectively. The values for coho salmon were similar to those for trout, while Atlantic salmon biomass is close to zero with the three Z values (Fig. 7). The expected available biomass for the period of our experimental fishing during 1996 was much greater with the lowest Z value than with the other two. The estimated catch for artisanal fishery for 1995 and 1996 was closer to the available biomass, with the highest mortality rate of 1.2 for Atlantic salmon (Fig. 7) and trout, although 1995 estimated catch for the latter showed a wider variability range and mean

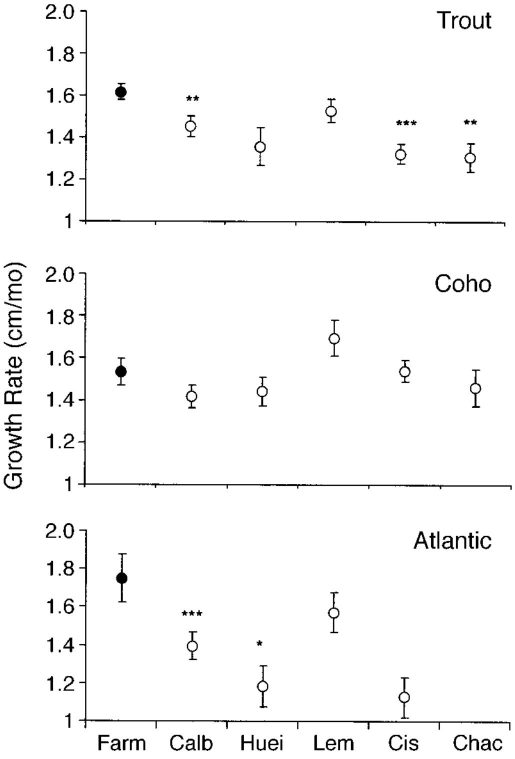

FIG. 6. Mean growth rate during the second year of age for captured individuals of each species (open circles) and of farmed individuals (solid circles).

TABLE 2. Number of escapees for each age class potentially recruiting to populations.

Species	Escape year	Age class (yr)						Total
		0+	1+	2+	3+	4+	5+	
Trout	1994		337 902	213 321	92 441			643 664
	1995		35 500	0	0			35 500
	1996		0	14 363	0			14 363
Total trout								693 527
Coho salmon	1993	0	43 820	0	0			43 820
	1994	17 890	1 083 970	13 479	84 251			1 181 700
	1995	0	289 253	0	0			289 253
	1996	0	89 759	0	0			89 759
Total coho								1 604 532
Atlantic salmon	1993	0	76 332	310 460	0	38 166	0	424 958
	1994	17 830	585 969	94 300	111 223	91 149	122 618	1 023 089
	1995	0	13 504	4 099	8 277	0	0	25 880
	1996	0	3 362	0	18 585	0	0	21 947
Total Atlantic salmon								1 495 874

closer to expected biomass with a Z value of 0.8. Estimated captures for coho salmon showed a range for Z of between 1.2 and 0.8 (Fig. 7). These estimates may not fully apply in the XI Region since, as mentioned above, we did not have sufficient detailed information on escapees there. However, catches declined in the XI Region through time at the same rate as they did in the X Region (Fig. 3).

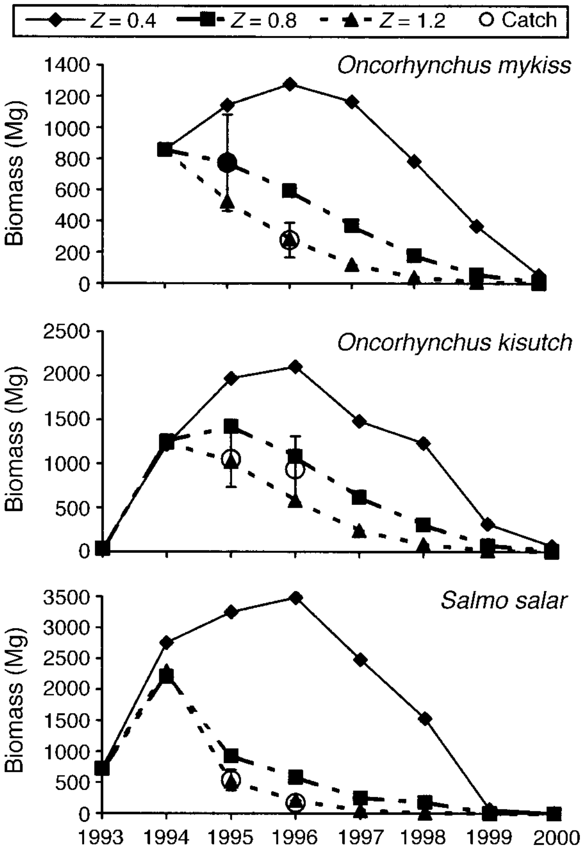

FIG. 7. Population size from escapes (1993–1995), and simulated projections to year 2000 according to three decay or mortality rates: $Z = 0.4, 0.8, 1.2$. Total artisanal biomass captures estimated for 1995 and 1996 are also indicated with a circle for each species (mean ± 1 SE).

Salmon abundance and distribution relative to native wild fish

In total, we captured 31 native fish species as a bycatch of coastal salmon fishing. Robalo (*Eleginops maclovinus*), huaica (*Macruronus magellanicus*), and jurel (*Trachurus murphy*) were the most frequent and abundant species. In general, the sites that produced the largest salmon captures had, at the same time, the lowest native fish catches and species richness (Table 1, Figs. 3 and 8). Native fish abundance in the catches was in general more even through time than that of salmon (Fig. 3).

Salmon feeding and food web

We analyzed stomach contents of 526 trout, 803 coho salmon, and 189 Atlantic salmon. From the contents of these stomachs we identified five main items: fish, insects, mollusks, crustaceans, and feed pellets, which is the food provided by salmon farms. At lower taxonomic levels, we recorded at least 42 different items that in turn comprised a much larger group of species, since in many cases, particularly in crustaceans and fish, it was only possible to identify down to genera, family, order, or phyla.

While the three salmon species included all five main items in their diet, there were some differences among them. Based on all the stomachs analyzed at all six sampling sites, we obtained the frequency of occurrence of each item in the three main species of salmon. Crustaceans were the most frequent item in the diet of trout, being present in 32.3% of the stomachs (Fig. 9). At a finer scale, the most abundant taxa among crustaceans were amphipods, decapods, and cirripedia. Although crustaceans were frequent in coho salmon, the

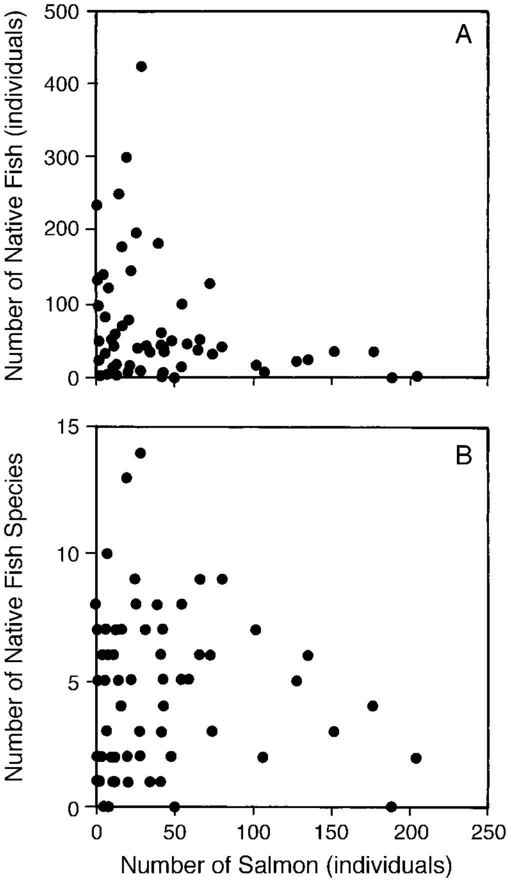

FIG. 8. (A) Relationship between the number of native fish and salmon (individuals) captured per site and date and (B) the relationship between the number of native fish species and salmon (individuals).

most common item in the diet of this salmon was fish (Fig. 9), whose digested remains were sometimes difficult to identify to specific level. School-forming fish such as anchovies (*Engraulis ringens*), sardines (*Sardinops sagax*), mote (*Normanichthys crockery*), silversides (*Odontesthes regia*), and the juveniles of huaica were the most frequent. On average, up to 25 silversides or 40 juvenile mote were found in a given coho salmon stomach, corroborating the pelagic feeding nature of the salmon. All three salmon species revealed some consumption of feed pellets, and this was more frequent in Atlantic salmon.

Numerical frequency analyses also indicated that crustaceans were by far the most frequent item in both trout and coho salmon diets, with representations of 80.2% and 80.1% respectively, while in Atlantic salmon the largest numerical representation was for feed pellets (63.5%) and fish (20.1%) (Soto 1997).

DISCUSSION

The massive release of salmon in the ocean associated with aquaculture could enhance wild populations of existing species such as *O. mykiss*, and introduce new ones such as *O. kisutch*, and *Salmo salar*. Our results from the experimental fishing and population extrapolations suggest that most salmon captured in the X Region during the study period were probably part of the remaining fish stock from the large escapes. There was little or no evidence of truly wild established populations.

Exotic species may be successfully introduced in the wild if they find proper environmental conditions or habitats, including food, and especially if they lack natural enemies such as predators and competitors that could control their numbers. In Southern Chile, coastal artisanal fishermen appear to have exerted a strong control on potentially thriving salmon populations, making salmon introduction and salmon fishery of wild populations unlikely in the short run, at least in the X Region. Comparison of simulation of escapees (Fig. 7) with the decline in C.P.U.E. in the experimental fishing (Fig. 3) indicates the highest mortality rate used was probably closer to reality. On the other hand, the experimental fishing reported here took place after salmon had been fished for more than a year after the accidental massive escapes. That could explain the better agreement between the available biomass predicted by this curve for 1996, and the total estimated catch, particularly for Atlantic salmon and trout (Fig. 7).

Free-living salmon, but not wild salmon yet

Captured salmon in Southern Chile are most likely those that have escaped, considering age structure, growth rates, and species composition of captured individuals (Figs. 5, 6, Table 3). Although we cannot tell exactly how long these salmon have been free, it is certainly about one year. We can also argue that most escaped salmon were caught by fishing, because their abundance was dramatically reduced toward the end of our study (Fig. 3), which also agrees with the simulated populations at the highest mortality rate (Fig. 7). Indeed, very recent experimental fishing carried out between November 1998 and April 1999, in control areas and near farm sites, shows a very low abundance or

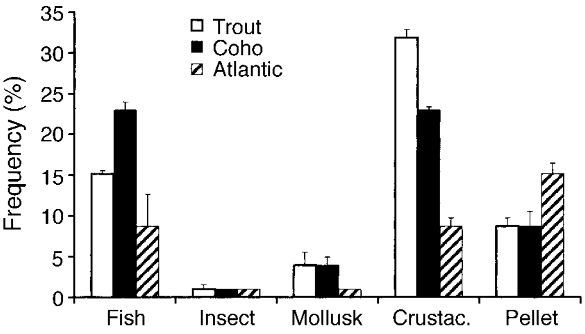

FIG. 9. Mean (+ 1 SE) frequency of occurrence of major items in the diet of the three species. All sites and dates are pooled.

TABLE 3. Percentage of each salmon species in total aquaculture production (by mass), in each region by the end of 1995, and reported escapees and captures in the experimental fishing.

	X Region			XI Region		
Species	Production (%)	Reported escapees (%)	captures (%)	Production (%)	Reported escapees (%)	Captures (%)
O. mykiss	28.8	19.3	43.9	10.3	27.0	16.1
O. kisutch	30.4	23.3	37.3	80.2	67.5	82.0
S. salar	37.5	57.4	17.4	9.5	4.8	1.7
O. tshawytscha	2.5	0	1.2	0	0.8	0

an absence of salmon (Cassigoli et al. 1999), which agrees with our predicted 1999 biomass with the highest mortality rate (Fig. 7). Another argument to support such a proposition is that salmon species composition and distribution in the experimental catches (Table 1, Fig. 2) resembled the relative abundance, by mass, of the species in aquaculture (Table 3). This is particularly true in the XI Region, where coho salmon, the most commonly farmed species, was the most frequently captured, while in the X Region trout represented a larger biomass proportion in the captures than for the reported escapees (Table 3). This was likely due to initially higher fishing pressures on the other two species (coho salmon and Atlantic salmon), that were larger in length but not mass.

Although the number of escaped salmon could have been large enough to produce reproductive populations in the wild, most of the escaped fish in the X Region probably did not survive to reproduce. Surveys performed by the Chilean Fishery Service (SERNAP) in the ocean area of Chiloé, X Region, reported a mean of 200 fishing boats involved more or less permanently in the coastal capture of salmon (and other native fish) during 1994 and 1995. Considering the mean C.P.U.E. ($kg \cdot net^{-1} \cdot d^{-1}$) we found for each species, we calculated a total salmon catch in this area, for the 1996 period, of 425 metric tons, with an estimated error of 20%. There were more captures during the first year after massive releases, when fish were closer to farms and fishermen could have captured >50% of escaped fish, consistent with the highest mortality rate used in the simulation (Fig. 7). Unfortunately there are no quantitative reports on this period, although regional news papers mentioned ~3–4000 metric tons captured between 1994 and 1995. Such volume also promoted attempts by fishermen to establish an open fishery, which started the conflict between fishermen and salmon farmers. Our catch estimates for 1995 probably only represent the last portion of that year (Fig. 7).

During our fishing the largest salmon were captured between November and April (Fig. 4), which left only the smaller individuals towards the end of the fishing period (December 1996). This probably reflects the general selective fishing pattern since the escapes took place. For this reason, the proportion of Atlantic salmon was much smaller in our captures than in the reported escapes (Table 3). On the other hand, Atlantic salmon apparently had the greatest fidelity to farm sites, as could be inferred from the high frequency of pellets in the stomach content (Fig. 9), and could be caught easily.

The possibility of the remaining free-living salmon forming sustainable populations would depend on density-dependent as well as density-independent factors, which are complex because both involve freshwater and marine habitat conditions. However, some of these adult salmon are likely to survive, especially coho salmon, which had the highest growth (Fig. 6), even though most captured individuals spent at least one year swimming free at sea. Highest growth rates can be found in coho salmon in the ocean when food and water temperature are adequate (Sandercock 1991, Ishida et al. 1998). Indeed, coho salmon showed some of the lowest levels of empty stomachs and the highest frequency of fish in the diet (Fig. 9). Yet, successful reproduction is needed in order to maintain wild populations, and the question of the availability of adequate breeding grounds and conditions in Southern Chile remains to be investigated.

It is possible that some of the largest and oldest salmon disappeared from the inner ocean fishing by April 1996 (Fig. 4) because they started reproductive migration into the rivers. In the case of coho salmon, between 40% and 80% of the individuals captured in March 1996 were sexually mature, showing well-developed gonads. Mature trout represented <15% of the population in March and April, and for Atlantic salmon there was no clear evidence of maturing individuals (Soto 1997). These numbers should have been much smaller during the first year, since most individuals were only at age 1+, and only a very small proportion of the decay rate (Fig. 7) could have been due to reproduction. Thus, reproductive escape could not have been >20% of total escaped salmon, and those were mostly coho. Indeed, coho salmon that escaped in the XI Region had higher chances to complete their natural maturation cycle, and may be successfully reproducing where suitable spawning rivers and rearing sites for juveniles can be found (Zama and Cardenas 1984). Similarly, the inner seas of Chiloé in the X Region host

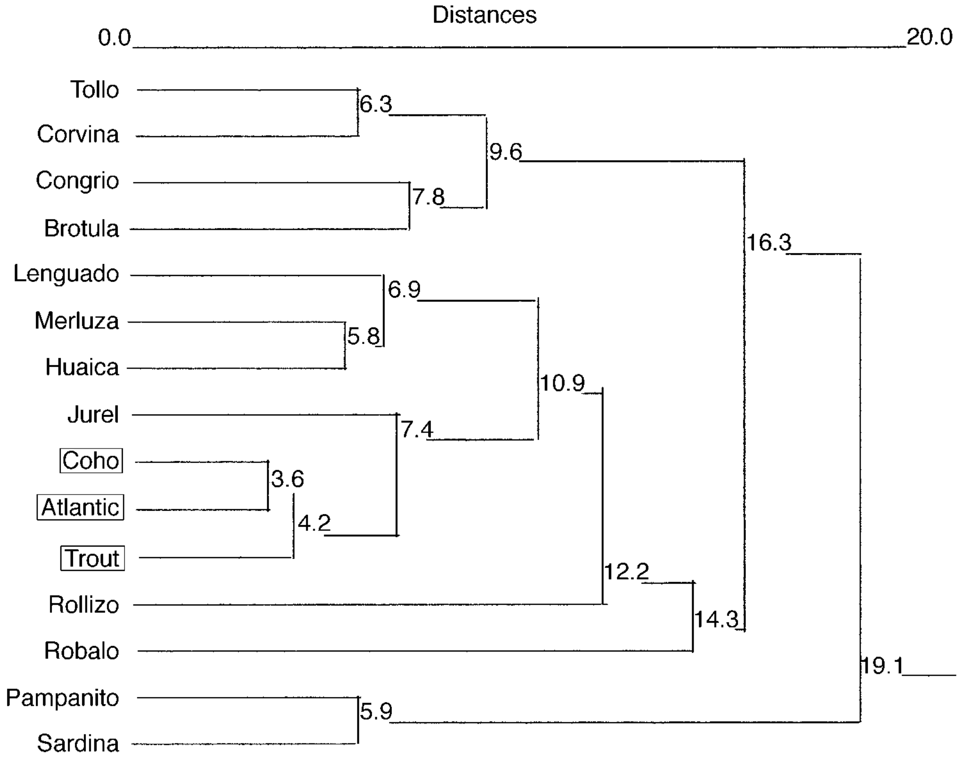

FIG. 10. Clustering of salmon and native fish based on frequency of occurrence of major group items in stomach content. The distance metric is Euclidean distance for an average-linkage-method tree diagram.

such habitats (Fig. 1) in the Reloncaví Fjord and connected hydrographic basins, such as the river basins of Puelo and Futaleufú further south. However, these basins are closer to Pichicolo, the control site (Fig. 1), far from the major escape areas. In the more dense salmon areas, in the X Region, close to Calbuco and Lemuy (Fig. 1), on Chiloe Island, there are mostly small rivers, which are likely to serve as reproductive sites, particularly for coho salmon. Since this species seems to maintain large populations based on many small reproductive sites and frequent straying (Sandercock 1991), such small rivers could be suitable. However, success may have been very low, as demonstrated by past and current electrofishing surveys of many of such suitable rivers. There, coho salmon juveniles have been mostly absent, representing <2% of total captures, while rainbow trout and brown trout reached >90% of the species captured (Wood 1997; D. Soto, I. Arismendi, and F. Jara, *unpublished manuscript*).

Atlantic salmon is the least likely to have successful reproduction, because a large proportion of escapees have been genetically modified to avoid maturation (Soto 1997). On the other hand, once free they do poorly at feeding on their own (Fig. 9), having the highest mean levels of stomach emptiness (42.3%), and the lowest growth rate (Fig. 6). Similarly, Atlantic salmon that escaped from farms in British Columbia are often reported in ocean catches and in streams, but with no reports of successful reproduction (McKinnell et al. 1997), until a very recent finding of a few individuals born from natural spawning in a small basin (Volpe et al. 2000).

Rainbow trout has been established in the country for over a century, and most likely some free-living individuals have achieved successful reproduction, thus generating a ''sea-run'' strain and perhaps modifying the genetic composition and variability of the existing populations (pre-aquaculture strains).

One species rarely captured in our experimental fishing was the chinook salmon (Table 1) even though we have registered frequent, small escapes of this species (F. Jara, *unpublished data*). There are also several reports of escapes going all the way to Argentina through the Futaleufú River on the Chiloé mainland (Fig. 1) (Grosman 1992; M. Pascual, *personal communication*). These salmon are apparently going to the open ocean and returning via deep waters of the inner ocean, as they are not being caught by coastal fishermen, but are caught occasionally by deep-water long lines (D. Soto and C. Moreno, *personal observations*). More surprising is the fact that these escapees probably belong to much earlier chinook ranching attempts (Mendez and Munita 1989). Most of the long-term sporadic reports of open ocean salmon catches refer to chinook. Comparable escapes of coho salmon have not been observed in the X Region.

Potential reciprocal effects with native fish

The largest native species numbers were found when salmon abundance was lowest (Figs. 3 and 8). Yet, it was not possible to determine clearly which was the cause and which was the effect, because there could be negative effects in both directions. Native species, which may have negative effects on salmon by behaving aggressively or by directly preying on them, include merluza (*Merluccius gayi*) and huaica (*Merluccius magellanicus*). However, salmon were the largest species caught during the experimental fishing, and therefore they were the most likely cause for native species decline when they were abundant. Salmon, particularly chinook and coho, in their natural habitats are placed as top predators in pelagic food webs where they act mostly as piscivorous fish (Welch and Parsons 1993).

In general, the diet and preferences of introduced salmon in Southern Chile reflect their natural feeding. For example, trout had a larger frequency of crustaceans but their diet also very often showed terrestrial material (i.e., insects) and terrestrial vegetation debris (Soto 1997). This was evidence of surface feeding in areas with freshwater input. Coho salmon feeding (Fig. 9) reflected a similar pattern to that observed in British Columbia or Alaska, that is, a very flexible diet including schooling fish and crustaceans (Sandercock 1991). A cluster analysis on the frequency of occurrence of items place the three salmon closer to each other than to native species (Fig. 10). This was partly due to their feeding on pellets, meaning that they all keep some degree of fidelity to farm sites by feeding near the salmon cages. Of the three species, coho salmon was the most likely to have an important impact on pelagic communities by feeding on fish (Fig. 9). In the event that large populations of this species become established, particularly in the XI Region, a larger impact from salmon feeding could be expected. However the native species that salmon may be mostly competing with (Fig. 10) are jurel, merluza, and huaica. With the possible exception of the last, they are threatened species themselves, due to open water overfishing, and it is possible that some resources (prey items) may be increasing as a result, particularly schooling fish. Thus, there may be an open niche for salmon in the Chile and Aysen inner oceans caused by fishermen.

A more complex situation could be expected from salmon feeding on crustaceans, since there are several groups involved, including larval stages of economically important crabs and planktonic crustaceans in the benthos. Here, we would expect direct competition with other fish and direct and indirect effects on benthic invertebrates. Such complex interactions certainly deserve further detailed studies.

Management implications

All effects and potential interactions between salmon and native organisms that have been mentioned would become of concern only in the case that some of the salmon species, particularly coho, would establish viable large populations. This establishment is rather unlikely because salmon are and will be, whenever available, an important alternative resource for coastal fishermen. New escapes are always happening, although frequency and volume have declined steadily since 1995 due to better building and monitoring of salmon pens. Thus, the conflict over free-living salmon ownership is momentarily solved in the X Region, since a large salmon biomass is no longer available for artisanal fishing.

If government and fisheries authorities eventually decide to avoid salmon colonization and naturalization in the Chiloé and Aysen inner seas, local artisanal fishing should be encouraged because it is probably the most efficient way to wipe escaped out salmon. Curiously, this is happening even without encouragement because, due to overfishing of native resources, salmon have temporarily become an alternative whenever available. On the other hand, ranching programs or other attempts to introduce salmon species do require special training programs for fishermen to protect reproductive runs and nursery areas. Hence, the introduction and prevalence of wild salmon populations in southern Chile will take place in more remote areas, and populations will last as long as they do not become the targets of artisanal fisheries.

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