Bird Predation on Juvenile Salmonids in the Big Qualicum Estuary, Vancouver Island

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RÉSUMÉ

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Margaret A. Birch

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BIRD PREDATION ON JUVENILE SALMONIDS IN THE BIG QUALICUM ESTUARY, VANCOUVER ISLAND

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ABSTRACT

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The impact of piscivorous birds on hatchery-reared juvenile chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon in Big Qualicum River was investigated over three years (1979-81) to determine both the extent of predation and the most effective means by which it could be reduced. Based on observations of feeding activity and censuses of birds taken several times daily throughout the release period, estimated numbers of chinook captured by birds within the first 2 km of the hatchery were 300,900-354,200 (10.4-12.2% of total release) in 1980 and 856,500-1,260,400 (21.5-31.7% of total release) in 1981. The main reason for the difference between the two years was that the 1981 chinook had severely-impaired vision, due to a dietary deficiency. Coho smolts suffered less substantial losses of 36,900-42,300 (4.9-5.6%) in 1980 and 42,100-65,300 (2.9-4.4%) in 1981.

Recommendations for reducing bird predation on Big Qualicum chinook included: a delay in release until early or mid-June when migratory birds such as Arctic loons (Gavia arctica) have disappeared; restriction of releases to tides and times of day when birds are the least effective at feeding; and a decrease in the length of release period to minimize the accumulation of predators, particularly Bonaparte's gulls (Larus philadelphia). Implementation of these recommendations in 1982 resulted in chinook predation rates that were only about 15% of those in 1980 and 5% of those in 1981.

Keywords: Big Qualicum, Bonaparte's gulls, chinook fingerlings, coho smolts, bird predation, hatchery release-schedules, salmonid enhancement.

RÉSUMÉ

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On a étudié, pendant trois ans (1979-1981), l'influence des oiseaux piscivores sur de jeunes saumons quinnats (Oncorhynchus tshawytscha) et cohos (O. kisutch) élevés en piscifacture et libérés dans la rivière Big Qualicum, pur déterminer l'importance de la prédation et les moyens les plus efficaces qui permettraient de la réduire. À partir d'observations sur l'activité alimentaire des oiseaux et de leur recensement effectué plusieurs fois par jour au cours de la période de remise à l'eau, le nombre de saumons quinnats capturés par des oiseaux en deçà de 2 km de la piscifacture a été évalué en 1980 entre 300,900 et 354,200 (de 10.4 à 12.2% du nombre total libéré) et en 1981 entre 856,500 et 1,260,400 (de 21.5 à 31.7% du nombre total libéré). La différence entre les deux années peut s'expliquer surtout par le fait que les saumons quinnats de 1981 avaient une vision très affaiblie, en raison d'une carence alimentaire. Les pertes ont été moins élevées pour les jeunes saumons cohos, se chiffrant en 1980 entre 36,900 et 42,300 (4.9 à 5.6%) et en 1981 entre 42,100 et 65,300 (2.9 à 4.4%).

Les recommandations suivantes ont été formulées pour réduire la prédation des oiseaux sur les saumons quinnats de la rivière Big Qualicum: attendre jusqu'au début ou à la mi-juin pour libérer les poissons, alors que les oiseaux migrateurs tels que le huart arctique (*Gavia arctica*) sont partis; limiter les périodes de remise à l'eau aux marées et aux heures du jour où les oiseaux se nourrissent le moins; et diminuer la durée de la période de remise à l'eau afin de réduire au minimum le rassemblement de prédateurs, en particulier les mouettes de Bonaparte (*Larus philadelphia*). À la suite de la mise en vigueur de ces recommandations, la prédation des saumons quinnats est tombée en 1982 à environ 15% du chiffre de 1980 et à 5% de celui de 1981.

Mots-clés: Big Qualicum mouettes de Bonaparte, tacons de saumon quinnat, jeunes saumons cohos, prédation par les oiseaux, calendrier de remise à l'eau de la piscifacture, mise en valeur des salmonidés.

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1: INTRODUCTION

Predation on juvenile salmonids has long been perceived as potentially a very important and serious problem in the maintenance of salmonid fisheries. Neave (1953) stated that freshwater conditions play the largest role in determining changes in the abundance of adult populations of pink salmon (Oncorhynchus gorbuscha) and felt that protection from predators should be a major consideration in establishing new runs or in building up stocks. Ward and Larkin (1964) considered that depensatory predation in the freshwater stage is likely to be the mechanism that maintains cyclic dominance in Adams River sockeye salmon (O. nerka). Other authors (e.g. Peterman and Gatto 1978) have subsequently considered the predation problem in light of the various salmonid enhancement schemes and suggested the critical need for field studies of predation mortality. Despite this concern, there has been very little careful work to quantify the amount of predation on juvenile salmonids or to elucidate the means by which it could be avoided or alleviated.

Of the studies that have been attempted, most have concentrated on estimating impacts of piscivorous fishes, and some (e.g. Foerester and Ricker 1941) have shown that reductions in fish predator numbers can lead to substantial increases in survival rates of juvenile salmonids. With one exception, there has been relatively little attention paid to bird predators. The exception is the common merganser, which has been the subject of a large number of impact and feeding studies as well as several predator control schemes. For example, Alexander (1979) calculated that mergansers on the Au Sable River in Michigan consumed an average of 22.1 kg of trout each winter. Elson (1962) estimated that smolt production increased four-fold, from 5,000 to 20,000, in a New Brunswick stream following institution of a four-year merganser and kingfisher control program. Similar conclusions were reached by Huntsman (1941). After one year of merganser control, the number of smolts descending the Margaree River on Cape Breton Island increased two-fold. Merganser control was also initiated in another Cape Breton study and found to be a particularly effective means of reducing predation, due to the slowness of return of the birds (Erskine 1972).

I have found only one study which attempted to quantify the extent of gull predation on juvenile salmonids. Mossman (Alaska Dept. Fish and Game 1959) investigated gull and tern predation on salmon smolts in the Kvichak River in Alaska. He reported an average of 2.0 smolts per bird stomach for Bonaparte's gulls, 1.3 for glaucous-winged gulls, 3.3 for short-billed gulls and 1.3 for Arctic terns. On the basis of these data, he estimated that gull predation could account for up to 12,000 potential adult spawners. Mossman (1959) concluded, however, that while possibly important locally, the relative abundance of salmon from one year to the next was probably not related to the size of the gull population.

The present study investigates the importance of bird predation, especially that by Bonaparte's gulls (Larus philadelphia), on hatchery-reared juvenile coho (O. kisutch) and chinook (O. tshawytscha) salmon in the Big Qualicum River. The Big Qualicum River is located about 17 km north of Parksville on Vancouver Island, British Columbia (Fig. 1a). It is a lake-fed coastal stream, 11.2 km long and 20 m wide, running from Horne Lake to Georgia Strait. A salmonid enhancement facility is located about 1.65 km upstream from the mouth of the river. The facility incorporates both water flow and water temperature control. It began operation in 1963 and now includes a spawning channel for chum salmon (O. keta), two concrete rearing channels for chinook salmon, gravel rearing channels for chinook and coho salmon, Burrows Ponds for rearing steelhead fry (Salmo gairdneri), and an experimental channel. These facilities enable annual productions of 50-60 million chum fry, three million chinook fingerlings, two million coho fry and one million coho smolts, as well as varying numbers of chinook fry, and steelhead fry and smolts. Chinook fingerlings are reared for 90 days to a length of about 7 cm, and coho smolts are reared for 14 months and released at a size of 15 cm. Chum fry usually migrate seaward throughout April and May, with peak numbers in early May. Coho smolts are released in mid-May, and chinook fingerlings are released throughout June.

The estuary into which the fish migrate is very small; the total area exposed at the lowest tides is about 0.14 km^2. This means that juvenile salmonids may often reach extremely high densities in the estuary during the migration period.

The aggregation response of bird predators to the fish in the estuary was initially documented over two years, 1979 and 1980, and combined with small numbers of feeding studies to generate estimates of predation. A cursory analysis of the data indicated that birds could be taking significant numbers of Big Qualicum chinook fingerlings, and that Bonaparte's gulls were likely to be the most important of the bird predators. This led to the initiation of a more intensive study in 1981. Unfortunately, in that year a large proportion (at least 80%) of the hatchery-reared chinook fingerlings were suffering from a dietary deficiency which severely affected their vision. This problem is thought to have resulted from a calcium-zinc imbalance in the food meal which led to cataracts being deposited in the fishes' eyes, and may have eventually caused total blindness in many cases. Therefore, many of the results from 1981 could not be extrapolated directly to other years, but a combination of results from all three years was sufficient to allow a set of recommendations for reducing predation to be drafted. A follow-up study was undertaken in 1982 to test the effects of several such recommendations.

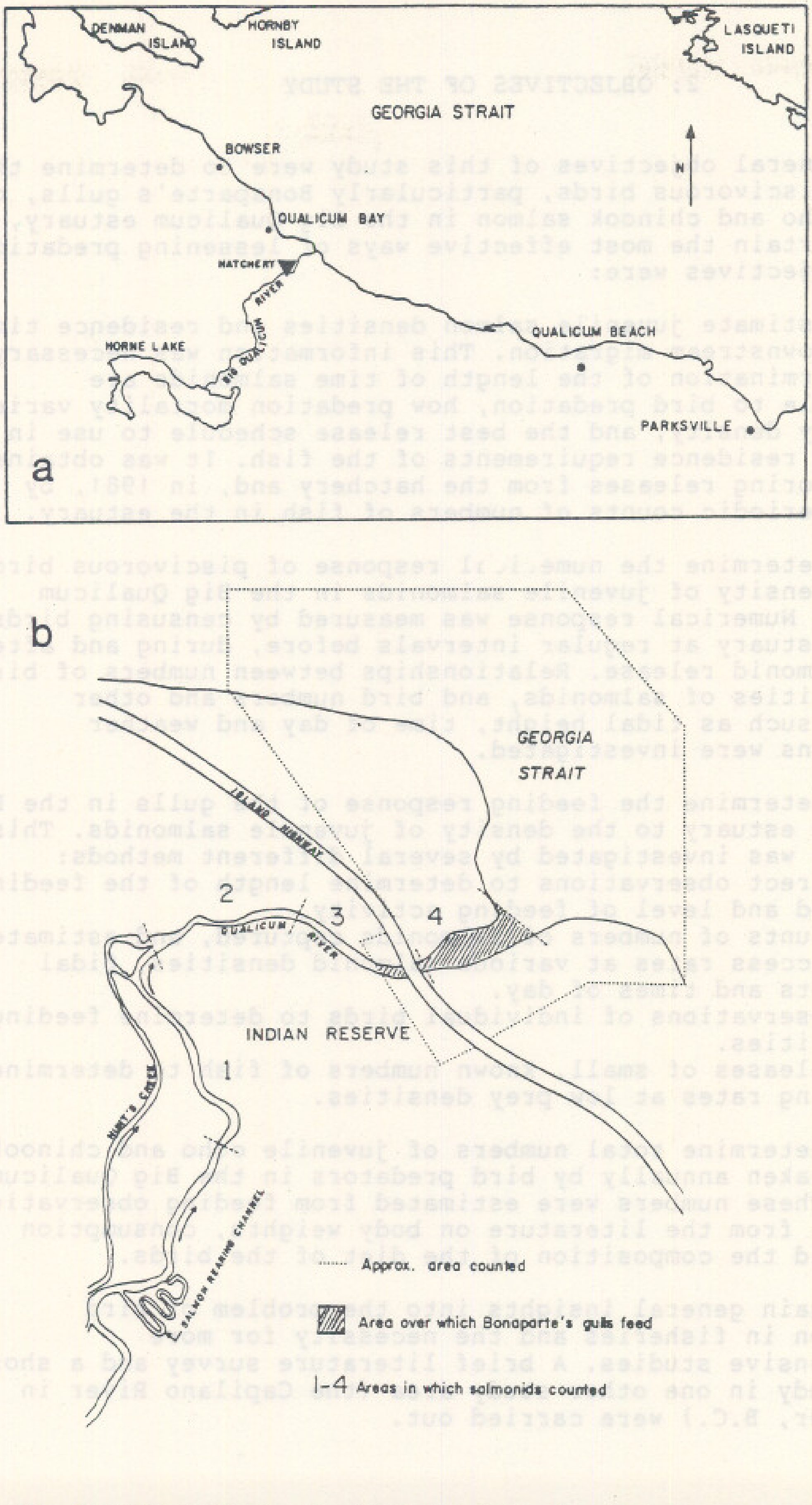


Figure 1. Big Qualicum River. a. Location map, b. Detail map showing approximate area over which birds were counted, feeding areas of Bonaparte's gulls and regions in the river where juvenile salmonids were counted.

2: OBJECTIVES OF THE STUDY

The general objectives of this study were to determine the impact of piscivorous birds, particularly Bonaparte's gulls, on juvenile coho and chinook salmon in the Big Qualicum estuary, and to ascertain the most effective ways of lessening predation. Specific objectives were:

1. To estimate juvenile salmon densities and residence times during downstream migration. This information was necessary for determination of the length of time salmonids are vulnerable to bird predation, how predation mortality varies with prey density, and the best release schedule to use in terms of residence requirements of the fish. It was obtained by monitoring releases from the hatchery and, in 1981, by making periodic counts of numbers of fish in the estuary.

2. To determine the numerical response of piscivorous birds to the density of juvenile salmonids in the Big Qualicum estuary. Numerical response was measured by censusing birds in the estuary at regular intervals before, during and after each salmonid release. Relationships between numbers of birds and densities of salmonids, and bird numbers and other factors such as tidal height, time of day and weather conditions were investigated.

3. To determine the feeding response of the gulls in the Big Qualicum estuary to the density of juvenile salmonids. This response was investigated by several different methods:
   a) Direct observations to determine length of the feeding period and level of feeding activity.
   b) Counts of numbers of salmonids captured, and estimates of success rates at various salmonid densities, tidal heights and times of day.
   c) Observations of individual birds to determine feeding capacities.
   d) Releases of small, known numbers of fish to determine feeding rates at low prey densities.

4. To determine total numbers of juvenile coho and chinook salmon taken annually by bird predators in the Big Qualicum River. These numbers were estimated from feeding observations and data from the literature on body weights, consumption rates and the composition of the diet of the birds.

5. To gain general insights into the problem of bird predation in fisheries and the necessity for more comprehensive studies. A brief literature survey and a short-term study in one other study area (the Capilano River in Vancouver, B.C.) were carried out.

3: CHINOOK AND COHO RELEASES AND RESIDENCY TIMES

In recent years, releases of both coho and chinook salmon from the Big Qualicum hatchery have been passive; that is, holding gates are opened to give fish access to the river, but the fish are not forced to leave. The rationale for not shunting the fish out is a general belief that they require some amount of time to adjust to ocean salinities, to forage in the estuary, and/or to imprint the cues needed to home to the river as adults. For the same reasons, coho smolts are given access about three weeks prior to the start of the chinook release. It is only the last 5% or less of each species that are forced out of the rearing channels.

In reality, there is little known about residency requirements for any stocks of coho or chinook, and nothing at all for the Qualicum stocks. The best study to date on residence times of chinook is that by Reimers (1973) on the Sixes River in Oregon. Reimers defined five life history types of chinook based on lengths of stay in the river and estuary. The most common type entering the ocean was that which remained in freshwater until early summer (having emerged between March and May) and spent only a brief time in the estuary. The most common type returning to spawn was that which remained in freshwater until early summer and then resided in the estuary until late summer or early fall. The latter type made up 90.6% of the spawners. It appears that there was selection for those fish spending a substantial amount of time in the estuary.

Such results may not apply to the Big Qualicum system as the Sixes River estuary, at approximately 4 km in length, is much larger than the Big Qualicum estuary. In fact, it is likely that residence requirements vary to some extent for every estuary and every stock of salmon. As residence requirements have some bearing on the ideal release schedule for hatchery-reared salmonids, it was necessary to determine how long the fish remained in the river following release from the hatchery. These data were also required to quantify the aggregation response of the birds.

Methods

In 1979, numbers of coho and chinook leaving the hatchery were inferred after all releases had taken place. Several hatchery personnel supplied daily estimates of the percentage of each species that had left. These estimates were then averaged and it was found that the first two-thirds of each migration fitted well to an exponential curve, and the last third to a straight line.

For coho, the equation

$$FL = 264{,}554e^{-0.43DS} \qquad (1)$$

where FL = number of fish leaving the hatchery each day
DS = number of days since the start of the migration

was used to estimate the numbers of coho that had left the hatchery each day for the first eight days of the release. The straight line

$$FL = 25{,}449 - 2{,}120.73DS \qquad (2)$$

was used for the remaining four days.

For chinook, the equations used were

$$FL = 731{,}258e^{-0.288DS} \qquad (3)$$

$$FL = 38{,}915 - 1{,}853DS \qquad (4)$$

Equation (3) was used for the first 14 days of migration, and equation (4) for the remaining seven days.

In 1980, estimates of numbers of fish leaving the hatchery were somewhat more reliable because they were obtained every few days during, rather than following, the releases. I interpolated between the estimates by assuming that fish left the hatchery at a constant rate during the intervening periods.

In 1981, the releases were monitored more closely, and frequent counts of numbers of fish in the river and estuary were made so that residence times could be determined. I recorded when the coho and chinook were first given access to the river and when access was prevented. At least once daily, I also visually estimated numbers of fish which had left the hatchery. Every 1-4 days, I swam the length of the river and censused the numbers of coho and chinook present. The area surveyed extended from the hatchery counting fence to the river mouth. The river mouth was defined as the lowest region of the estuary where, at low tide, visibility was not obscured by the mixing of fresh and saline waters.

For the purpose of the counts, the river was divided into sections where fish had previously been found to congregate. I then censused the maximum feasible proportions of these areas. Generally, the fish in approximately half the river were counted, and the estimate was doubled. The river was also divided along its length into four areas separated by prominent landmarks, to enable comparison of relative numbers of fish residing in the upper and lower regions (Fig. 1b).

Residence period was estimated separately for each distinct release by making several simplifying assumptions about the rate fish entered the river from the hatchery and the rate they left the river for the ocean. Rate of entering the river was assumed to be constant between periods when estimates of numbers of fish leaving the hatchery were obtained. An hourly rate was calculated by dividing the number of fish leaving the hatchery between two successive times by the number of hours between the times. It was then assumed that the number of fish leaving the river hourly was some constant proportion of the number present the previous hour. A lag-time of one hour was employed because on the two occasions when releases were monitored sufficiently carefully, it took approximately one hour for fish to appear in the estuary.

Under these assumptions the number of fish, N, present in the river at any time, t, is given recursively by the equation

$$N_t = N_{t-1} + c_1 - c_2 N_{t-1} \qquad (5)$$

where c_1 = number of fish entering the river hourly (= a constant, or zero)
c_2 = proportion of fish leaving the river hourly

Equation (5) can be generalized to give

$$N_t = \frac{c_1}{c_2}\{1 - (1 - c_2)^n\} + (1 - c_2)^n N_{t-n} \qquad (6)$$

where n = number of hours between the present time, t, and some time in the past at which the population size was known.

The solution to this equation is given by

$$N_t = c_1\{\sum_{j=0}^{n-1} (1 - c_2)^j\} + (1 - c_2)^n N_{t-n} \qquad (7)$$

To calculate the number of fish present in the estuary at any given time, a series of equations of the type (7) was used. The number of equations depended on the number of different estimates of c_1 that were made during each release. The final equation in each series represented the first post-release underwater count of the fish present in the estuary. (A count was always carried out within 24 h of closure of the access gates at the hatchery.) As the solution to this equation was known, the constant, c_2, could then be calculated. The other river counts were used in equation (7) with $c_1 = 0$ to calculate the rate fish left the estuary between releases.

Results

The timing, duration and size of the releases of juvenile coho and chinook salmon from the Big Qualicum hatchery in 1979, 1980 and 1981 are summarized in Table 1. The last date in the third column represents the time at which less than 5% of the salmonids remained. In all cases, fish left the hatchery rapidly once they were given access. For example, in 1979 and 1980, 60% of the chinook left the hatchery within the first three days of release.

Several differences between the 1981 releases and those from the two previous years are evident. In 1981, both the chinook and coho releases began earlier and the chinook release took place over a shorter time span. The bulk of the migration lasted for a period of less than 11 days, compared to 21 and 26 days in 1979 and 1980, respectively. In addition, in 1979 and 1980, releases were not interrupted once fish had been given access, but in 1981 the chinook migration was staggered so that there were about five distinct releases of different sizes. Some of the 1981 releases were forced. (The fish are forced out by one or more of the following methods: levels of water in the rearing channels are dropped, amount of water flowing in the river is increased, food is withheld from the fish, or fish are seined from the channels.) All releases made in 1979 and 1980 were passive.

Tables 2 and 3 give the total estimated numbers of coho and chinook in the river between and following the 1981 releases, and proportions of the totals found in different parts of the river. The river was divided into four regions: area 1 represents that part of the river immediately below the hatchery and free from any tidal influence, area 2 is the uppermost part of the river penetrated by the salt wedge, area 3 represents the length of river above the highway bridge that experiences considerable tidal influence at tides above 3 m, and area 4 comprises the estuary below the highway bridge (see Fig. 1b).

It is evident that few fish stayed in the river or the estuary for long. For example, there were only slightly more than 100,000 coho remaining in the river on May 16 after a release of over 1,000,000 fish the previous day. The largest number of chinook counted was 41,700 on June 4 following a release of 1,100,000 fish during the previous three days. It also seems that there were only two areas where fish congregated in large numbers: immediately below the hatchery and immediately above the highway bridge. There were rarely large numbers of fish present in the area between the highway bridge and the river mouth except at the peak of migration when no attempt was made to determine densities.

Residence times estimated on the basis of these data and equation (7) are presented in Table 4 for each release and for the intervening period between releases. Coho had a slightly

Table 1. Timing and sizes of coho and chinook salmon releases in the Big Qualicum River in 1979, 1980 and 1981.

Year	Species	Timing of Releases	Total Duration (days)	Number Fish Released
1979	Coho	May 22 - Jun 3	13	615,200
1979	Chinook	Jun 4 - Jun 24	21	2,539,100
1980	Coho	May 19 - May 29	11	750,200
1980	Chinook	Jun 7 - Jul 2	26	2,895,900
1981	Coho	May 8 - May 16	9	176,300
1981	Coho	May 15 - May 20	6	1,300,000
1981	Chinook	May 8	1	4,000
1981	Chinook	May 11	1	60,000
1981	Chinook	0830 May 19 - 2030 May 19	0.50	200,000
1981	Chinook	0945 May 20 - 1130 May 20	0.073	50,000
1981	Chinook	2000 May 25 - 0930 May 28	2.56	2,100,000
1981	Chinook	1500 May 30 - 1700 May 30	0.083	13,000
1981	Chinook	1500 Jun 1 - 1300 Jun 2	0.92	1,100,000
1981	Chinook	1405 Jun 5 - 1700 Jun 5	0.12	430,000
1981	Chinook	1700 Jun 5 - 1730 Jun 6	1.02	20,000

longer residence time than chinook, although residence periods for both species were extremely short. Up to 12.52% of the chinook entering the river from the hatchery left the estuary each hour. This means that more than 50% of the chinook present in the system left the estuary within six hours and almost 90% left within 17 h.

Table 2. Estimated number of juvenile coho salmon between the Big Qualicum hatchery and river mouth, and the proportions of the total found in different areas of the river in 1981. Average salinities increase through areas 1-4.

Date	Area 1	Area 2	Area 3	Area 4	Total Estimated
May 12	0.94	0.04	0.03	<0.01	4,300
13	0.96	0.04	<0.01	<0.01	2,900
14	0.84	0.16	<0.01	<0.01	1,600
16	0.60	0.26	0.05	0.09	>102,300
18	0.81	0.07	0.12	<0.01	75,800
22	0.45	0.23	0.31	<0.01	59,000
25	0.24	0.06	0.59	0.11	24,600
29	0.04	0.17	0.78	0.01	12,600
June 1	<0.01	0.04	0.96	<0.01	7,200
4	0.04	0.08	0.86	0.02	2,800
7	<0.01	<0.01	0.83	0.17	2,000
9	<0.01	0.02	0.95	0.03	1,200

The percent leaving each hour was considerably lower, and therefore residence time was somewhat higher, for the forced chinook releases compared to to the passive releases. Between releases, the rate of leaving the estuary was always lower than during releases, suggesting that small numbers of fish reside in the estuary for a few days.

The high rate at which the fish left the estuary is more obvious when numbers of fish present in the system are plotted over time (Fig. 5). There was a dramatic decline in fish numbers immediately after each release. For example, for the May 25-29 chinook release (Fig. 5b), 99.46% of the 2,100,000 fish released had left the estuary within 24 h of closure of the holding gates.

Discussion

The fact that few of the hatchery-reared coho and chinook reside in the river or estuary suggests that either the fish do not require a residence period, or else that other factors force them out. It is possible that intraspecific or interspecific interactions result in most fish being displaced downstream, or that the estuary is unable to provide food for the large numbers released into it.

Results also indicate that most fish spend little time adjusting to ocean salinites. Whether this adversely affects survival rates is unknown. Conte *et al.* (1966) and Wagner *et al.* (1969) investigated the development of osmotic and ionic

Table 3. Estimated number of juvenile chinook salmon between the Big Qualicum hatchery and river mouth, and the proportions of the total found in different areas of the river in 1981. Average salinities increase through areas 1-4.

Date	Area 1	2	3	4	Total Estimated
May 11	0.85	0.12	0.03	<0.01	400
12	>0.90	0.03	0.04	<0.03	>21,600
13	0.84	0.10	0.06	<0.01	11,900
14	0.91	0.07	0.02	<0.01	5,500
16	0.88	0.12	<0.01	<0.01	900
18	0.95	0.02	0.02	<0.01	400
22	0.14	0.70	0.13	0.03	600
25	0.85	0.02	0.06	0.07	500
29	0.42	0.10	0.38	0.10	11,400
June 1	0.52	0.27	0.12	0.09	1,800
4	0.05	0.09	0.83	0.03	41,700
7	0.01	0.04	0.34	0.61	17,400
9	0.10	0.18	0.72	<0.01	1,700

regulation in juvenile coho salmon and juvenile chinook salmon, respectively. In both studies, percent survival in sea water at various salinities was monitored over a 30-day period. Both gradual and immediate transition tests were conducted for fish of different ages and sizes. Juvenile coho salmon attained almost 100% survival when exposed to 30 ppt salinity by immediate transition if transfered at least 200 days after fertilization. Juvenile chinook attained at least 80% survival under the same conditions 140 days after fertilization. Survival rates of chinook transferred to salinities of 25 ppt, 120 days after fertilization, also exceeded 80%. For gradual transitions, survival rates in all cases were even higher.

From these data it seems unlikely that Big Qualicum stocks require a residence period to adjust to estuarine salinities. Coho are reared for more than 200 days and chinook are generally reared for at least 200 days post-fertilization before being released. The fast growth rates attained by the hatchery-reared fish may also enable rapid acclimation. Wagner et al. (1969) found that small fish exhibiting fast growth were better regulators than larger slow-growing fish. Further, even if fish descend the river rapidly, they are probably able to acclimate gradually by using freshwater layers on the surface of the estuarine and ocean waters.

Whether or not it would be beneficial to the fish to spend time feeding in the estuary, it is likely that such a small estuary could provide food for large numbers of fish for a brief

Table 4. Estimated residence times for coho and chinook salmon in 1981. Residence times are expressed in terms of the percent of fish present in a given hour that leave the estuary the following hour.

Species	Time	Size of Release	Nature of Release	Percent Leaving per Hour
Coho	May 15-May 18	1,262,670	Passive	5.79
	May 18-May 22	37,330	Passive	0.66
	May 22-May 25	0		1.17
	May 25-May 29	0		0.76
	May 29-Jun 1	0		0.76
	Jun 1-Jun 4	0		1.34
	Jun 4-Jun 7	0		0.52
	Jun 7-Jun 9	0		0.87
Chinook	May 8-May 11	4,000	Passive	3.21
	May 11-May 12	60,000	Forced	4.34
	May 12-May 13	0		2.67
	May 13-May 14	0		3.31
	May 14-May 16	0		3.34
	May 16-May 18	0		2.06
	May 19-May 22	250,000	Passive	9.99
	May 25-May 29	2,100,000	Passive	12.52
	May 30-Jun 1	13,000	Passive	5.10
	Jun 1-Jun 4	1,100,000	Forced	5.64
	Jun 5-Jun 7	450,000	Forced	7.49
	Jun 7-Jun 9	0		4.35

period of time only. More research is needed to determine the capacity of the system in this respect.

It would also be instructive to determine residence periods in the Big Qualicum River in other years. The above data were gathered in an unusual year when many fish had impaired vision. The partially-blind fish were probably incapable of holding in current and, consequently, may have left the estuary faster than healthy fish. In fact, it was noted that the affected fish, detectable by their faded colouration, passed through the system more quickly than fish of normal colouration, and also tended to travel downstream backwards or sideways in groups of one or two, rather than in schools.

4: THE AGGREGATION RESPONSE

If bird predation is significant, it will be necessary to know the speed, magnitude and timing of their response to releases of hatchery-reared fish so that a release schedule that avoids as much predation as possible can be devised. This is particularly true in the present system as many birds that key into the releases are migratory species en route to nesting grounds. If fish are released at the peak of the birds' migration, they may suffer substantially more predation mortality than they would if releases could be delayed until the bulk of the migrants have passed through. If other factors make it infeasible to delay release, it is possible that predation could be alleviated by controlling sizes of the releases and the time of day or tidal height at which releases are initiated.

A list of bird species recorded regularly in the Big Qualicum estuary is contained in the Appendix. Only the most common piscivorous species are considered in the present report. These include gulls, loons, mergansers, harlequins and scoters. Harlequins and scoters, although not usually classified as fish-eating birds, foraged heavily on Big Qualicum chinook in 1981. Brief descriptions of the species investigated are given below.

Bonaparte's Gulls (Larus philadelphia)

Bonaparte's gulls are small black-headed birds with a wing-span of about 80 cm and a body length of 30 cm (Robbins et al. 1966). Their flight and feeding are tern-like in manner. Euphasids, polychaetes and fish form the major prey sources (Bent 1921). They are distributed throughout North America, excluding the interior of the central-western United States and parts of eastern Canada. In British Columbia, they nest in the northern and central interior regions and winter along the southern coast. They form nests in trees in woodland deciduous forests. Northward migration occurs between March and June. Early flocks are mostly composed of adults, but by mid-May juveniles are more abundant. Fall migration back to southern areas begins in August.

Bonaparte's gulls were the most abundant bird predators observed in the Big Qualicum area during migration of juvenile coho and chinook salmon.

Larger Gulls

Several other species of gulls were present in the estuary. The most prevalent and largest of these was the glaucous-winged gull, Larus glaucescens, with a body length of 56 cm (Robbins et al. 1966). Its range extends along both the eastern and western shores of the Pacific Ocean. Nesting occurs on rocky islets along the coast (Guiget 1967). Glaucous-winged gulls are omnivorous opportunists, feeding on fish, invertebrates, molluscs and even other birds (Trapp 1979). In cities, they are often seen scavenging at garbage dumps.

Mew gulls (L. canus), California gulls (L. argentatus) and Thayer's gulls (L. argentatus thayeri, a subspecies of herring gull) were also present. Unlike glaucous-winged gulls, these species nest in the interior of British Columbia. Their food habits are similar to those of the glaucous-winged gull.

In the present study, larger gulls were not identified individually, but were all grouped together with glaucous-winged gulls, the most common species.

Loons

Large flocks of Arctic loons (Gavia arctica) were observed frequently in the study area. Smaller numbers of the common loon (G. immer) were also seen on occasion. In North America, Arctic loons winter along the Pacific coast from Alaska to Baja, California. They breed in the north from Alaska to Baffin Island. Migration to breeding grounds occurs in late April and early May. Their diet consists of fish, crustaceans, molluscs, aquatic insects and plants (Palmer 1962).

Mergansers

Both the common merganser (Mergus merganser) and the red-breasted merganser (M. serrator) were recorded in the study area. The red-breasted merganser was relatively much less common and was not included in the analyses.

Common mergansers breed throughout British Columbia as far north as the tree limit (Guiget 1967). They are common along coastal rivers and in estuaries (Salyer and Lagler 1940). Food habits of mergansers have been intensively studied because of their role in fish predation (e.g. Munro and Clemens 1937, Salyer and Lagler 1940, Elson 1962, Alexander 1979). Mergansers feed upon small fish, crustaceans and aquatic insects and, to a limited extent, upon fish eggs (Munro and Clemens 1937).

Harlequin Ducks (Histrionicus histrionicus)

The harlequin winters on the Pacific coast from San Francisco northward to the Aleutian Islands. It breeds along rivers and streams of the Coast Range and in the interior east of the Rocky Mountains, from the Mackenzie River south to Oregon and west to Montana.

Harlequin ducks migrate to breeding grounds in spring, with males returning to sea in mid-June and females and young in the fall (Guiget 1967). They feed primarily on crustaceans, molluscs, and insects (Cottam 1939), although they are reported to consume plants and fish as "incidental" prey items (Ainley and Sanger 1979), and have been observed preying upon herring eggs (Cleaver and Franett 1945, Bayer 1980).

Scoters

Three species of scoters were found near Big Qualicum River: the common scoter (Oidemia nigra), white-winged scoter (Melanitta deglandi) and surf scoter (M. perspicillata). Of these, surf scoters were the most common. Breeding grounds of surf scoters extend from the 60th parallel north to the Arctic Ocean. They winter along the entire Pacific coast from Alaska to southern California. Common scoters winter on the sea along the Aleutian Islands and from southern Alaska to northern Washington. Both surf and common scoters move northward in April and May and return to the wintering grounds in September and October. White-wing scoters nest over a large part of North America, extending eastward as far as Lake Winnipeg. In British Columbia they breed in the interior, although non-breeding individuals are present along the coast during summer.

Scoters feed largely on molluscs, crustaceans and insects and occasionally small fish (Guiget 1967, Ainley and Sanger 1979). There are also reports of scoters eating herring eggs (Bayer 1980), and marine plants (Vermeer and Vermeer 1975).

Methods

Birds present in the Big Qualicum estuary were counted several times daily before, during and after, the coho and chinook releases in 1979, 1980 and 1981. At each census, the time of day, tidal height, percent cloud-cover, strength of the wind, degree of rain and amount of surf action were recorded. The last three variables were ranked on a scale of zero to three: 0-none, 1-light, 2-moderate, 3-heavy. These factors were recorded primarily to enable determination of whether they had any effect on numbers of birds present. Weather variables also affected the accuracy of some censuses. In particular, it was difficult to accurately count birds feeding off the mouth of the river when surf was high.

At each census, activities of the birds were also recorded: whether they were feeding, searching, resting on water, resting on land, or in flight.

Birds were censused from dawn to dusk approximately every two hours in 1979, every three hours in 1980, and every four hours in 1981. In 1981, additional censuses were carried out for some bird species during the main salmonid releases. Counts were made from May 5 to June 26 in 1979, April 6 to July 14 in 1980, and May 8 to June 16 in 1981. In 1979 all species of birds in the estuary were recorded, including sandpipers and other small shorebirds, but as 9 x 50 binoculars were used, the range did not extend far beyond the river mouth. In 1980 and 1981, small non-piscivorous birds were not counted, and a 20-45x telescope was used to extend the range to approximately 1 km offshore from the river mouth (see Fig. 1b).

Stepwise multiple regressions were performed on the census data from 1980 and 1981 to ascertain which factors were the most important determinants of bird numbers in the estuary. Factors considered were:

1. Time of day
2. Tidal height (as an index of the depth of the water)
3. Time of season (numbers of days since the first day of counts)
4. Percent cloud cover
5. Amount of rain
6. Amount of wind
7. Surf action
8. Number of chum
9. Number of chinook fingerlings
10. Number of coho fry
11. Number of coho smolts

Quadratic and interaction terms were introduced into the regression equations to control for non-linearities between these factors and bird numbers, and for correlations between the different factors. Results of the analysis are not presented in detail; only the strength and direction of the correlation between bird numbers and each factor is discussed at length. Variables making a significant contribution to the multiple regression equation (those with coefficients significantly different from zero by F-tests at the $p = .05$ level) are first identified. For each correlation mentioned, probability levels are then computed on the basis of t-tests of the significance of the appropriate partial correlation coefficient (controlling for contributions of the other variables entered into the regression).

Results

1979 and 1980:

Figures 2 and 3 show daily numbers of juvenile chum, coho and chinook salmon leaving the hatchery in 1979 and 1980, and numbers of various species of birds present in the estuary during this time. In both 1979 and 1980, Bonaparte's gulls exhibited the most striking numerical responses (Figs. 2a and 3a). In 1980, peak numbers of Bonaparte's gulls corresponded closely to the peak in chum fry numbers and also occurred a few days after the start of the releases of coho smolts and chinook fingerlings. In 1979, there was a pronounced response to the chinook release, but little response to the chum and coho.

The magnitude of the response to chinook was greater than that to coho in both years. Regressions on the 1980 data showed that number of chinook was the most important factor determining numbers of Bonaparte's gulls present throughout the season, and

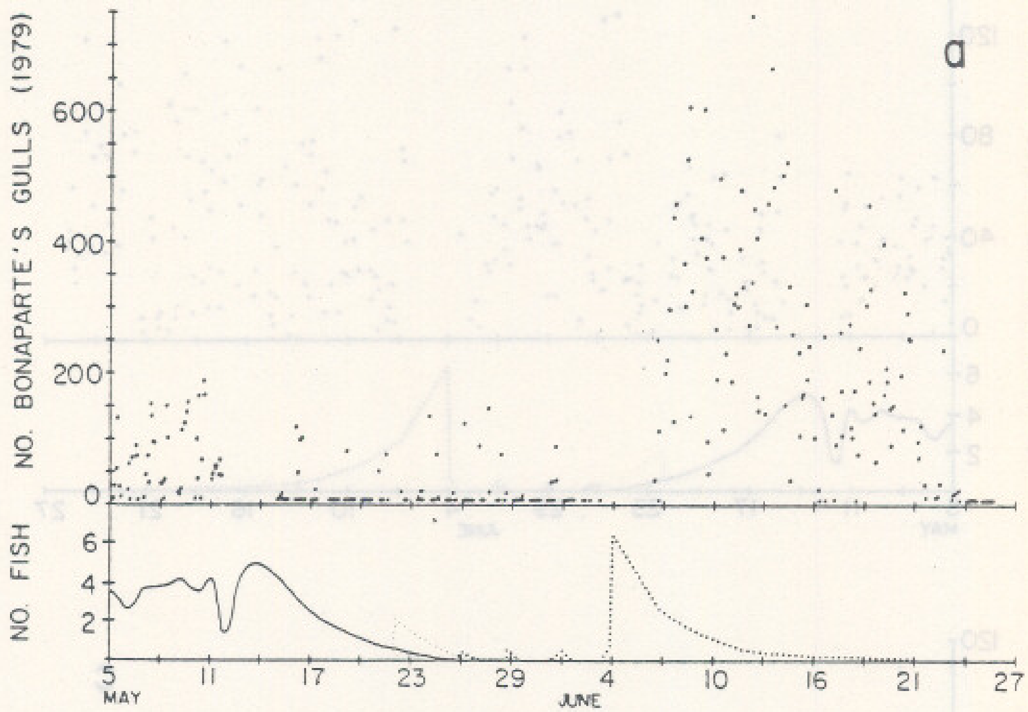


Figure 2. Numbers of piscivorous birds in the Big Qualicum estuary and daily numbers of juvenile chum, chinook and coho leaving the hatchery in 1979. Fish numbers have been plotted on different scales. One unit on the vertical axis represents 500,000 chum fry, 100,000 chinook fingerlings or 100,000 coho smolts. ——— chum fry, ••••••• chinook fingerlings, ·········· coho smolts. a. Bonaparte's gulls.

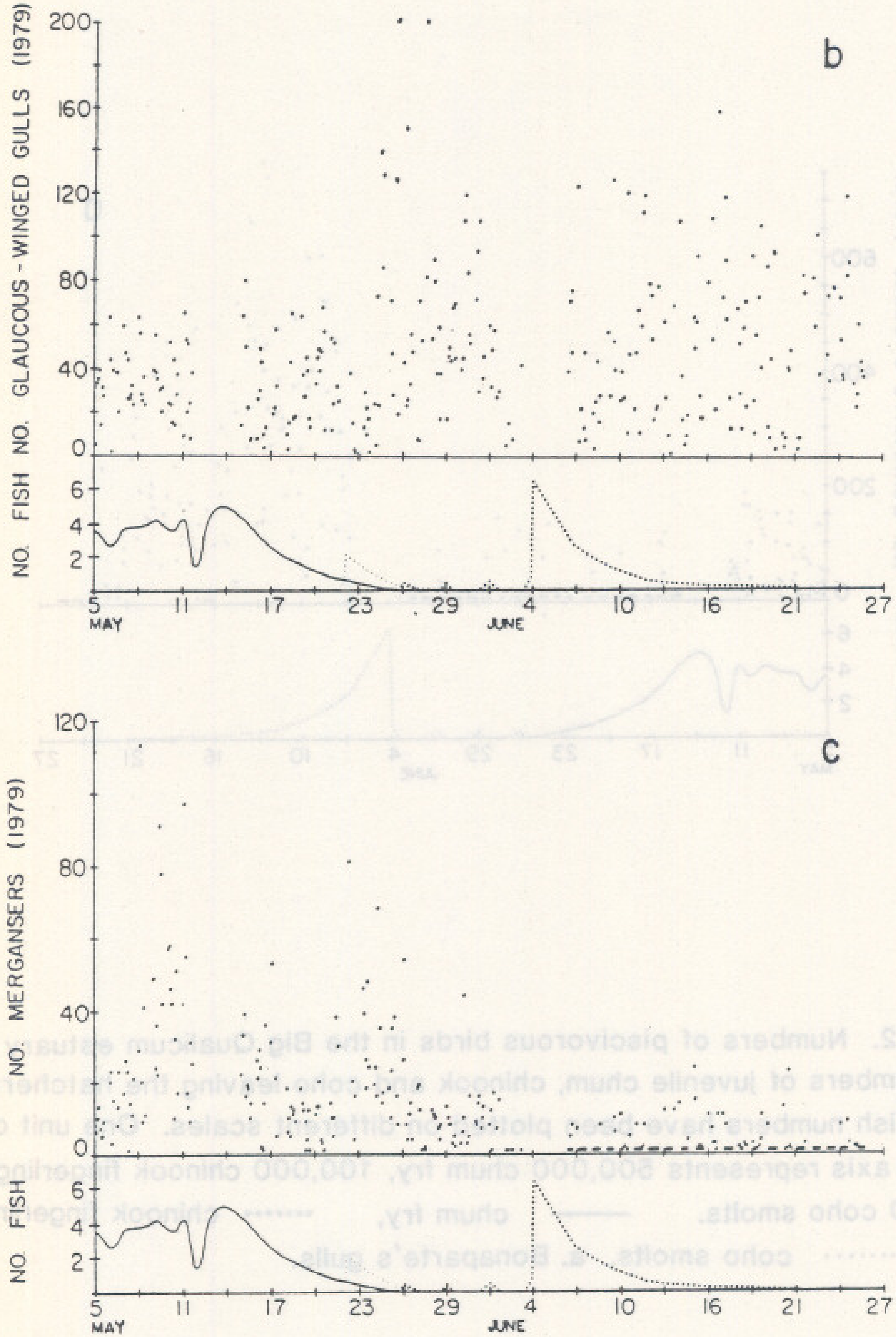


Figure 2 cont. b. glaucous-winged gulls, c. common mergansers.

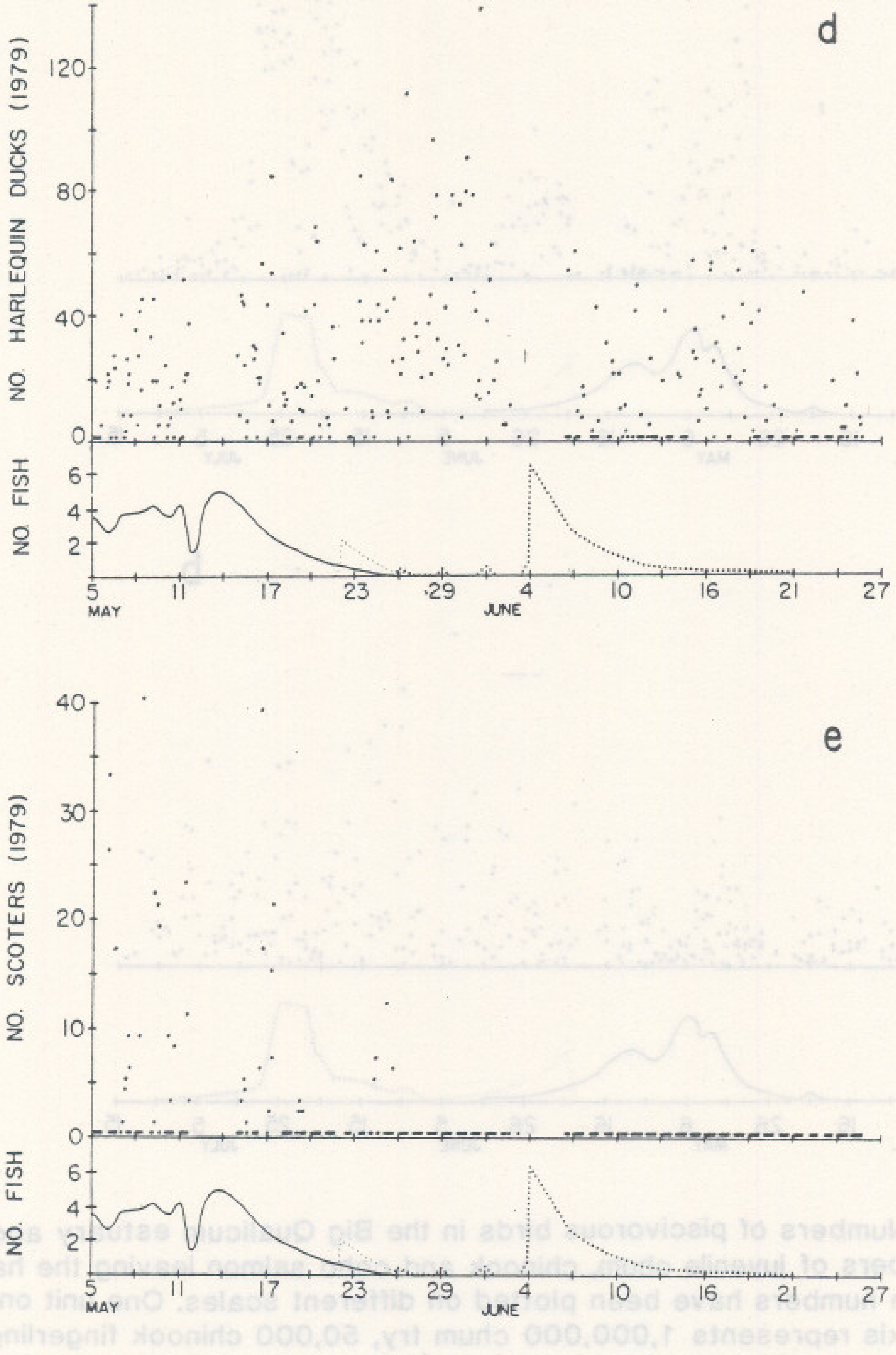


Figure 2 cont. d. harlequin ducks, e. scoters.

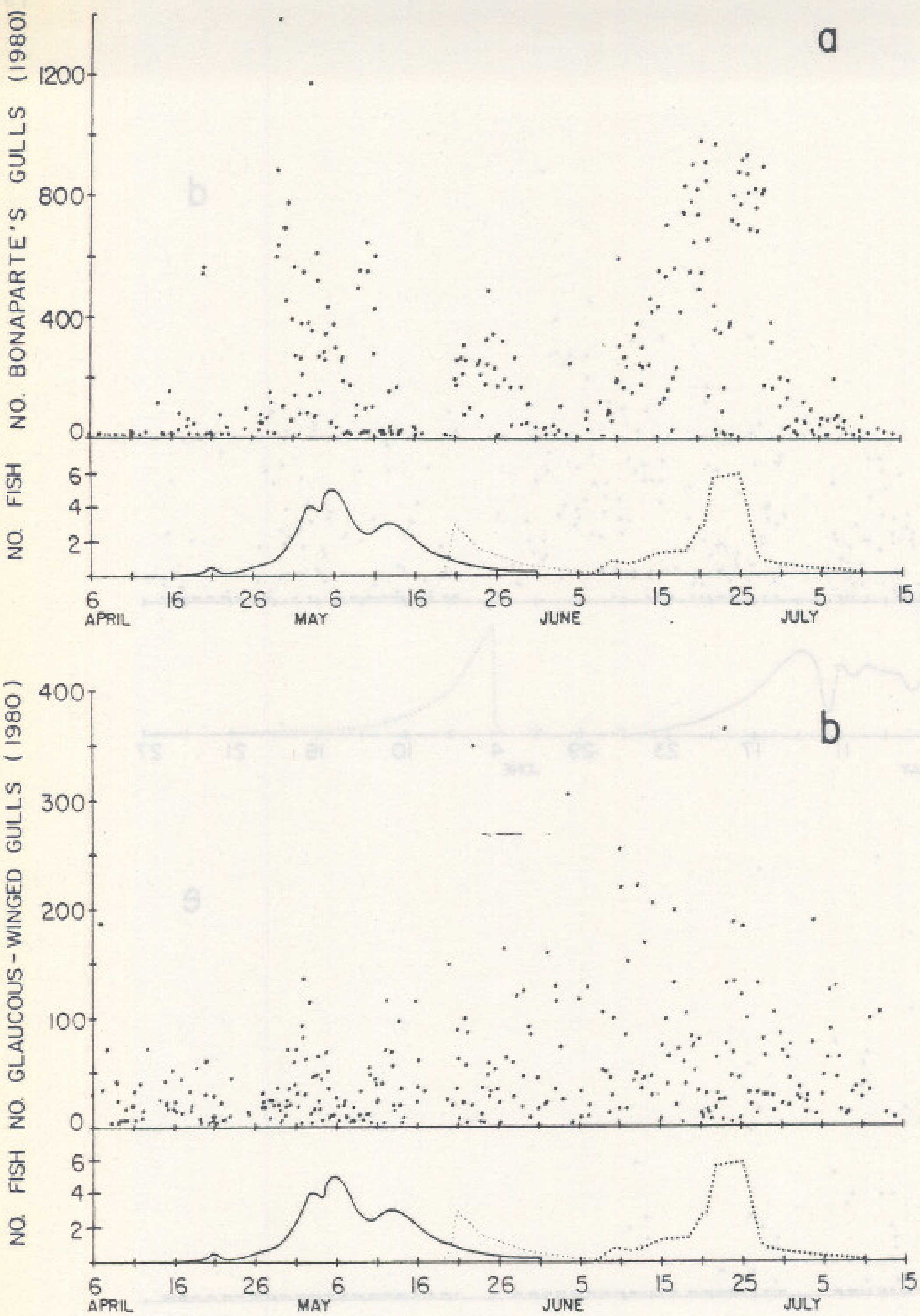


Figure 3. Numbers of piscivorous birds in the Big Qualicum estuary and daily numbers of juvenile chum, chinook and coho salmon leaving the hatchery in 1980. Fish numbers have been plotted on different scales. One unit on the vertical axis represents 1,000,000 chum fry, 50,000 chinook fingerlings or 50,000 coho smolts. ——— chum fry, ... chinook fingerlings, ... coho smolts. a. Bonaparte's gulls, b. glaucous-winged gulls.

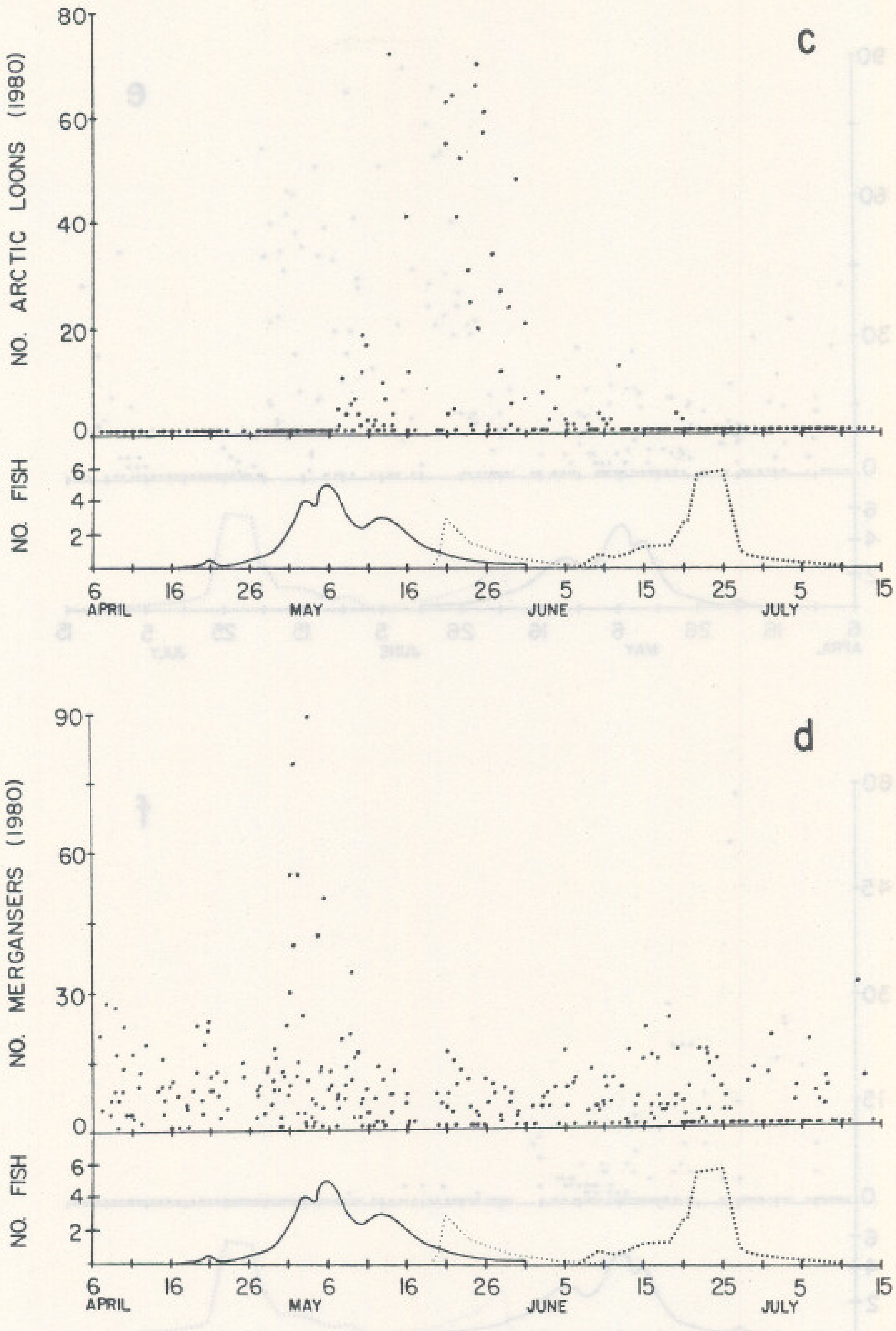
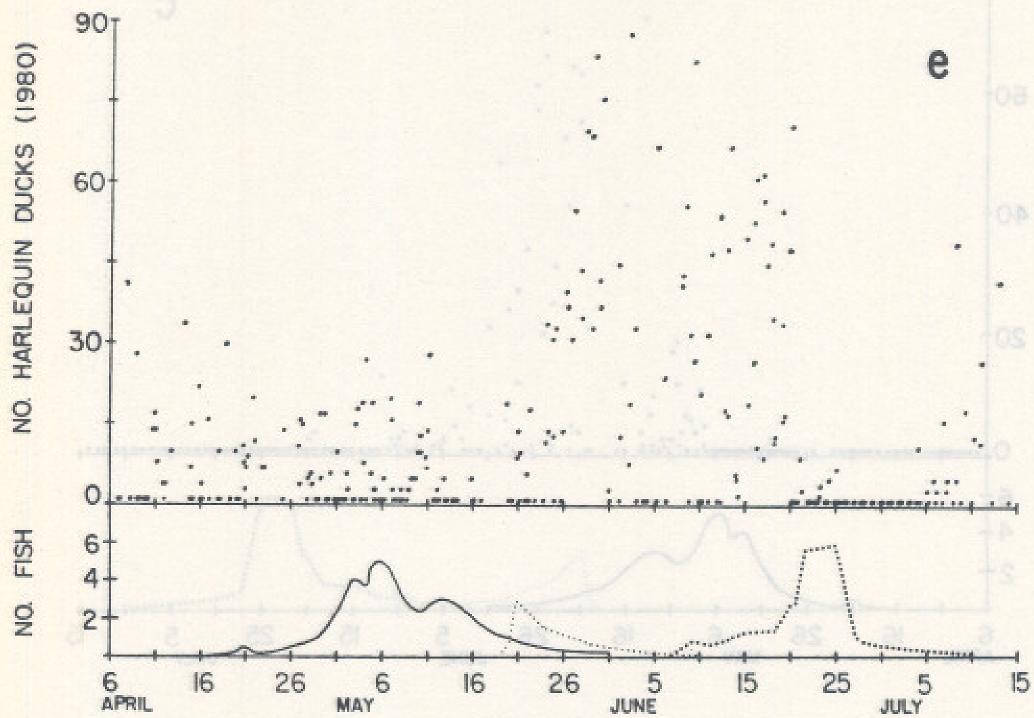


Figure 3 cont. c. Arctic loons, d. common mergansers.



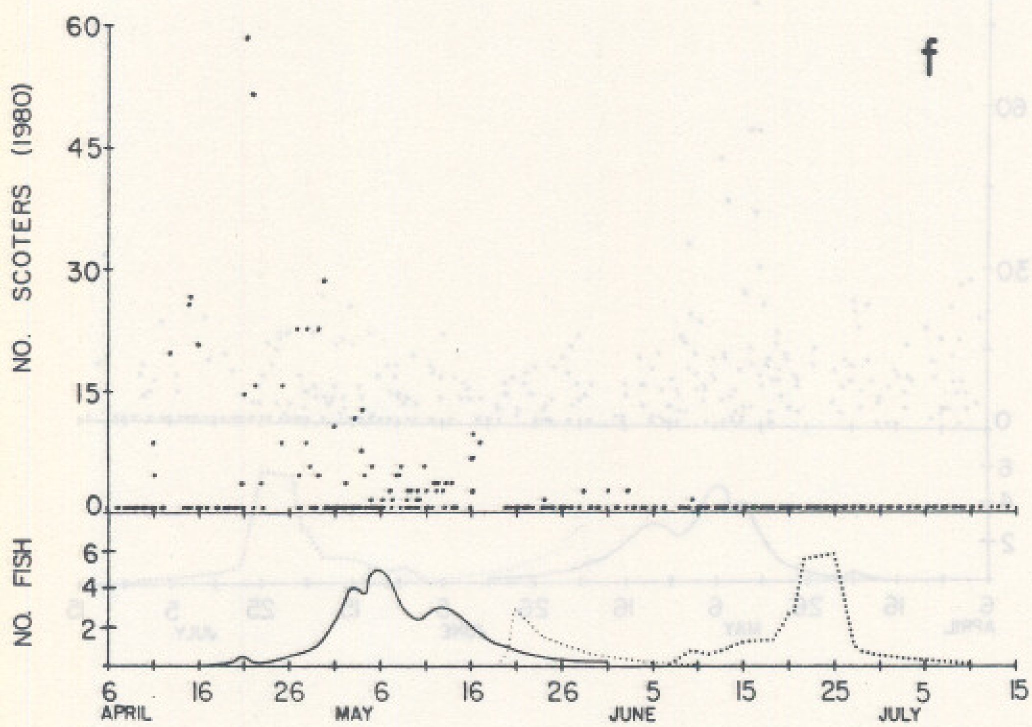


Figure 3 cont. e. harlequin ducks, f. scoters.

tidal height was the second most important variable. Numbers of Bonaparte's gulls were positively correlated with chinook numbers ($p < .001$) and negatively correlated with tidal height ($.01 < p < .05$). Coefficients of weather variables (factors 4-7 above) and abundances of other species of fish were not usually significant (F-tests, $p > .05$). There was also no significant seasonal influence on gull numbers for the time period covered ($p > .05$).

For the data obtained during the chinook migration, number of chinook and tidal height explained 12.9% of the variance in total Bonaparte's present.

The abundance of glaucous-winged gulls in 1980 did not seem to bear any direct relationship to numbers of juvenile salmonids, although they appeared to increase gradually throughout the season (Figs. 2b and 3b). In stepwise regressions of these data the seasonal factor was almost invariably the first to be entered into the regression equation (positive correlation, $p < .001$). There was also a positive correlation ($p < .001$) between tidal height and gull abundance. For most regressions performed, the variables entered into the equation explained less than 10% of the variation in gull numbers.

The most important factor affecting the abundance of Arctic loons at the mouth of the Big Qualicum River in 1980 was the number of coho smolts present (positive correlation, $p < .001$, Fig. 3c). Multiple regressions indicated that there was also a strong seasonal component to loon abundance, with a decrease in numbers occurring over the duration of the data collection ($p < .001$). Arctic loons had almost totally disappeared from the Qualicum area by the time of chinook release. From the regressions, the only other variables that influenced numbers of Artic loons were time of day (negative correlation, $p < .001$) and degree of wind or surf action (negative correlation, $p < .001$). Loons were more abundant during early morning than at other times of day. The negative correlation between degree of wind or surf action and loon numbers may reflect observation difficulties rather than a true relationship.

During the coho smolt release, the variables time of season, time of day, wind conditions, number of chinook and number of coho smolts explained 56.9% of the variation in loon numbers.

It appeared that numbers of mergansers in the estuary were not correlated with numbers of coho or chinook ($p > .05$ in both cases, Figs. 2c and 3d), possibly because mergansers, unlike other birds in the area, also fed upstream from the census stations. The number counted in the estuary at any one time was probably a variable proportion of the total number feeding along the river. In 1980, merganser numbers were positively correlated with tidal height ($p < .001$), and negatively correlated with time of season ($.001 < p < .01$) and time of day ($p < .001$). They were more likely to be down in the estuary at high tides, early in the season and early in the day.

In both years, numbers of harlequin ducks peaked in late May and early June (Figs. 2d and 3e). Their abundance was not significantly related to numbers of juvenile salmonids ($p > .05$). Peaks in numbers were probably mainly the result of male harlequin ducks returning to sea from the breeding grounds at that time of year.

In both years, there was no numerical response by scoters. Scoters exhibited a pronounced seasonal decline ($p < .001$, Figs. 2e and 3f) and by mid-May they were rare in the Qualicum area. No other variables affected their abundance significantly ($p > .05$ in all cases).

<u>1981</u>:

There are a number of differences between the data collected in 1981 (Fig. 4) and that collected during the two previous years. In 1981, chinook releases occurred earlier and were more distinct from each other, the chinook were affected by a nutrient deficiency, and the magnitude of the response by birds was considerably greater for all species concerned. The latter difference is probably related to the first two.

Bonaparte's gulls reached a peak of almost 1,700 in the Big Qualicum estuary in 1981 (Fig. 4a). As in 1979 and 1980, there was little numerical response by Bonaparte's gulls to the releases of coho smolts (no correlation, $p > .05$). There was also little detectable response to the first release on May 11 of 60,000 chinook fingerlings. Responses to the remaining four chinook releases are shown in Fig. 5 on a larger scale. In the latter three cases, Bonaparte's numbers tracked chinook numbers closely (Figs. 5b-d). For all four releases there was a lag of only 3-40 h between maximum Bonaparte response and maximum chinook numbers. The speed of the response was sometimes remarkably rapid. For example, on June 1 at 1500h, two chinook rearing channels were opened and the fish were forced out. At 1610 h, fish began to appear regularly in the estuary. At 1605 h, 72 Bonaparte's gulls were counted in the entire census area (Fig. 5c). A check of the shoreline for 3 km either side of the estuary revealed no additional Bonaparte's gulls. Nevertheless, at the next count at 1720 h, an hour and ten minutes after the appearance of the chinook, there were 619 Bonaparte's gulls present, almost all of which were feeding. By 2110h that evening there were 1,222 Bonaparte's gulls in the estuary.

Usually, the response to decreases in chinook numbers was also fast. The main exception is the June 1 release (Fig. 5c). In this case, chinook did not reach such low numbers between releases as they did for the other three cases. As chinook numbers waned, Bonaparte's numbers appeared to start to fall

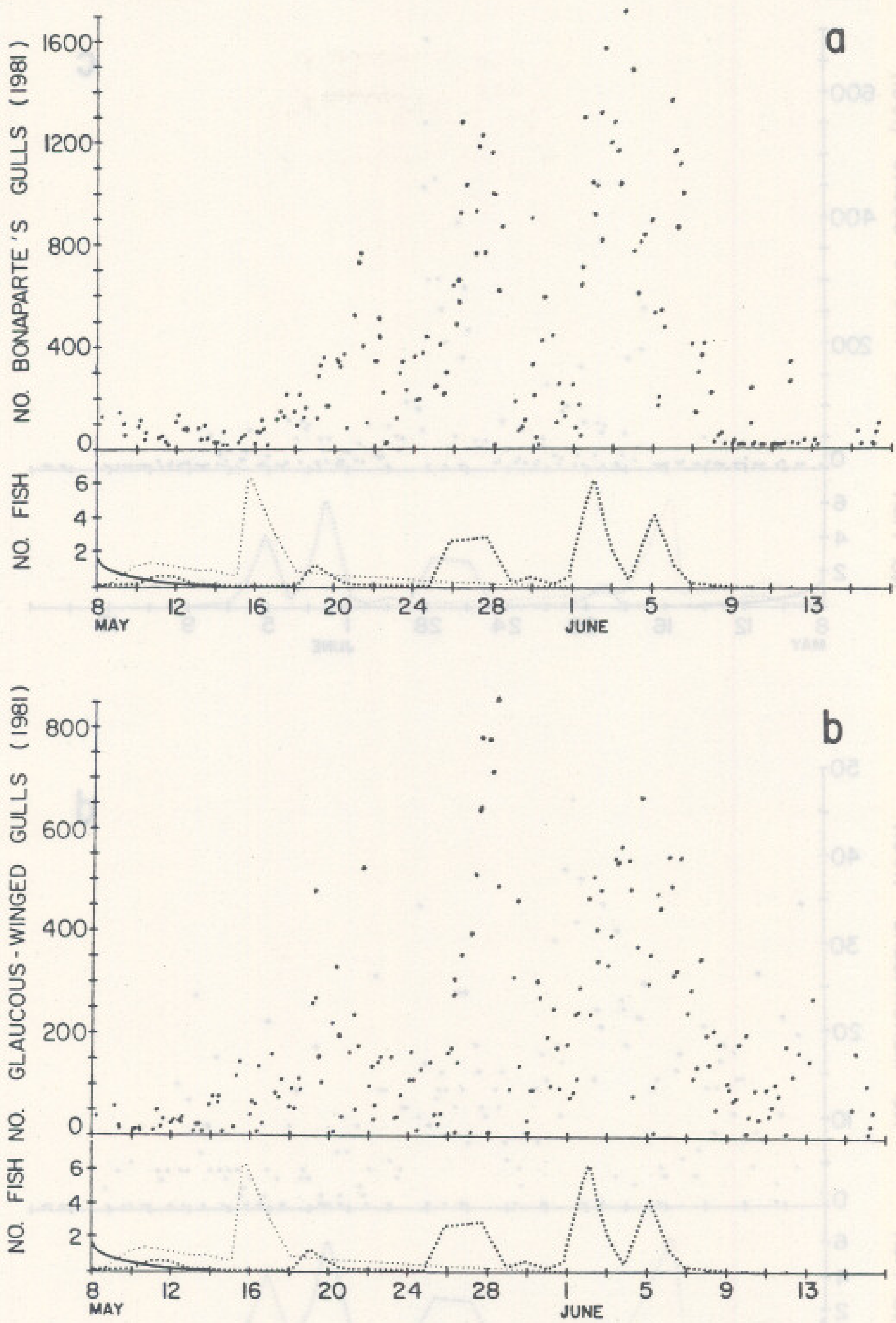


Figure 4. Numbers of piscivorous birds in the Big Qualicum estuary and daily numbers of juvenile chum, chinook and coho salmon leaving the hatchery in 1981. One unit on the vertical axis represents 100,000 of each salmonid. ——— chum fry, ······ chinook fingerlings, ········ coho smolts. a. Bonaparte's gulls, b. glaucous-winged gulls.

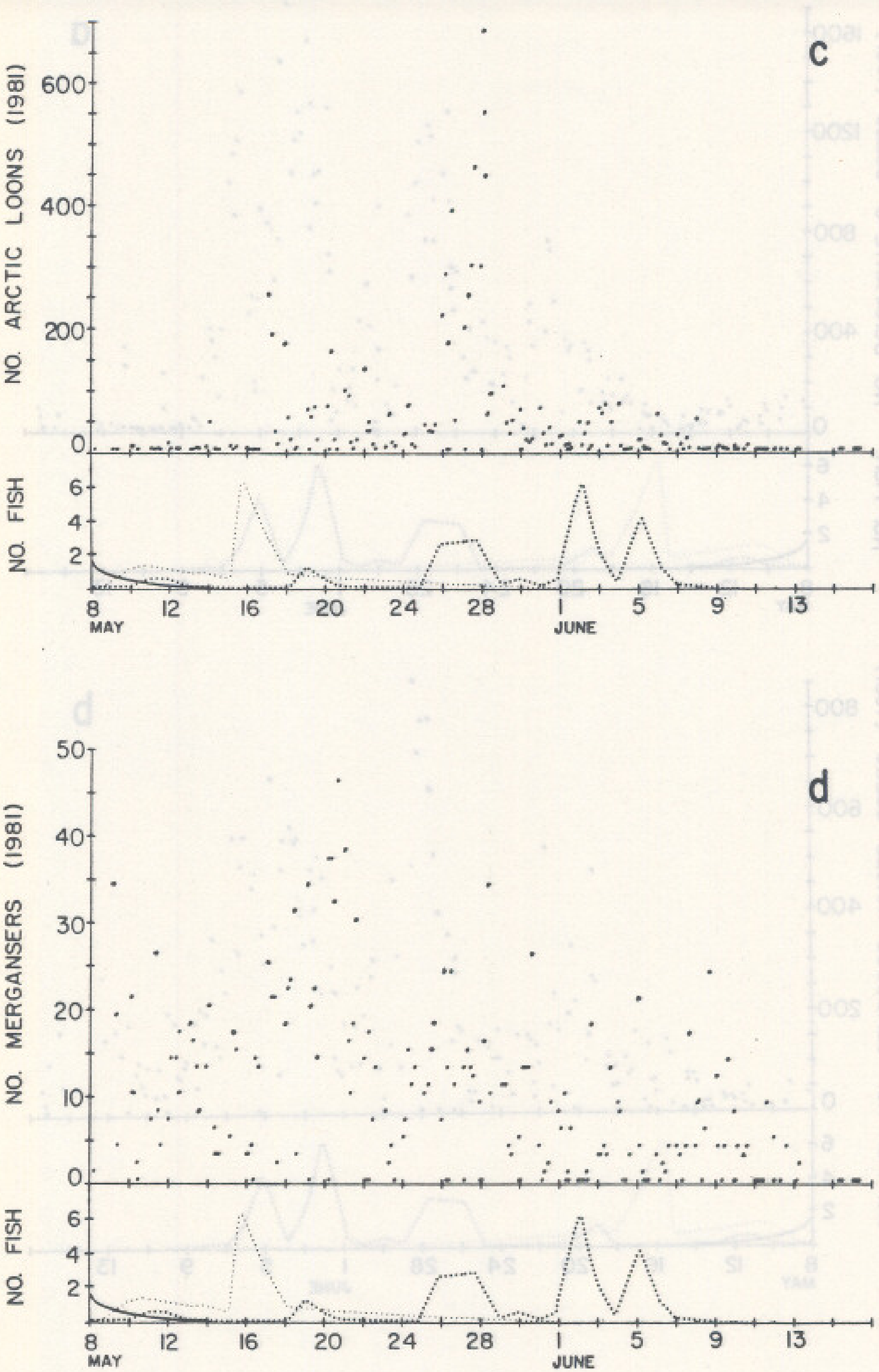


Figure 4 cont. c. Arctic loons, d. common mergansers.

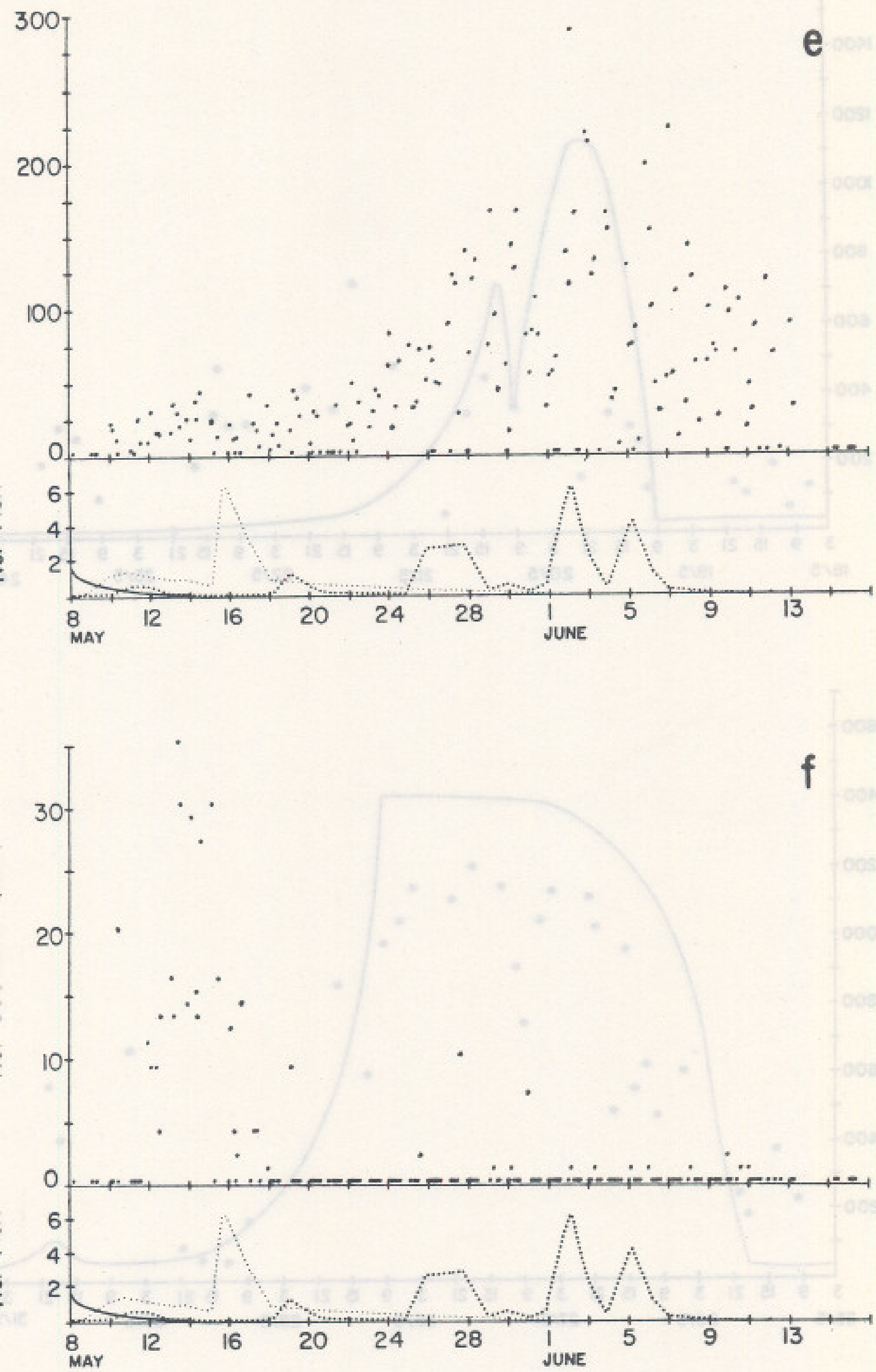


Figure 4 cont. e. harlequin ducks, f. scoters.

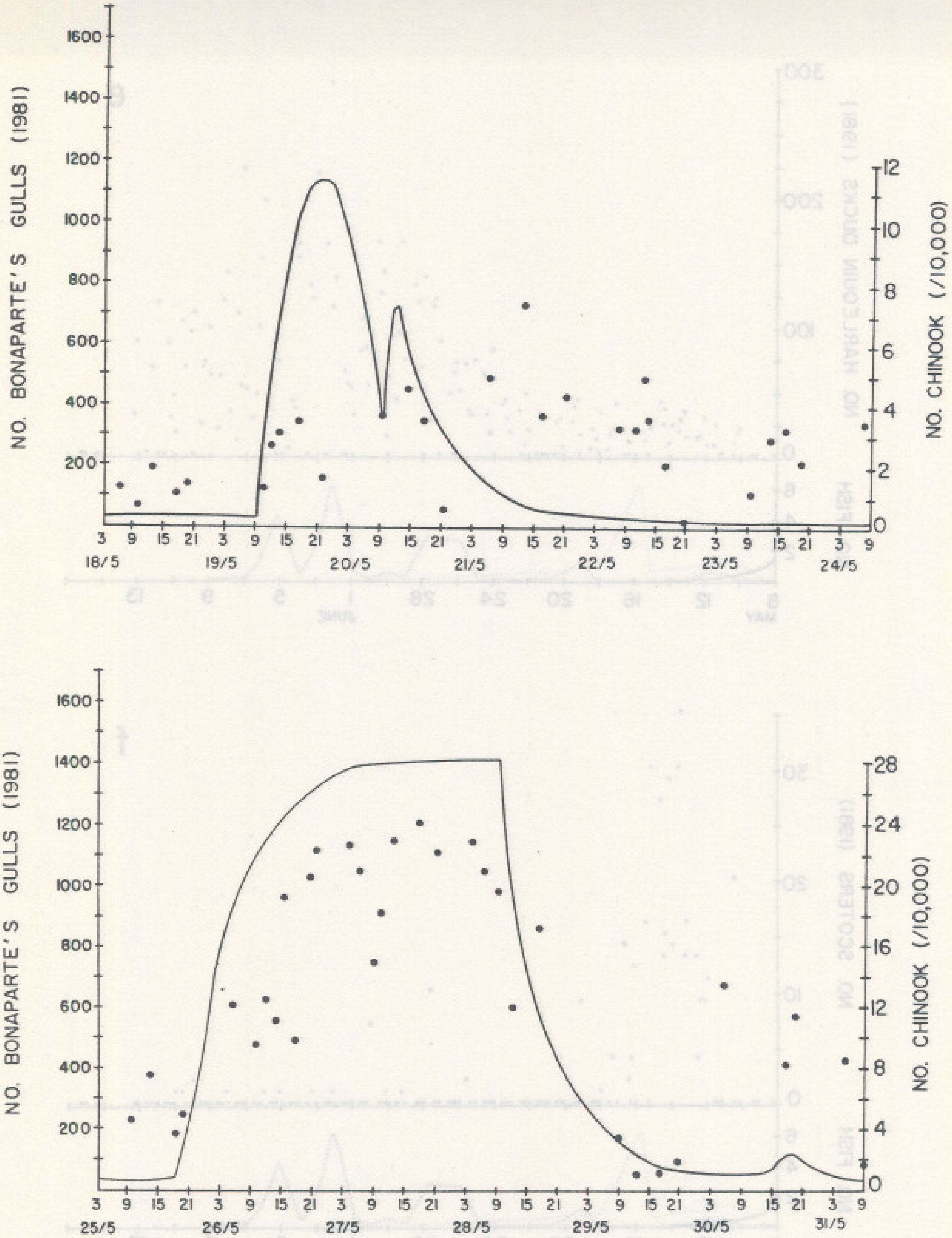


Figure 5. Aggregation response of Bonaparte's gulls to four separate releases of juvenile chinook in the Big Qualicum estuary in 1981. The first level of numbers along the horizontal axis represents the time of day measured in hours from midnight. The second level gives the day and month of the counts.

• numbers of Bonaparte's gulls, — estimated numbers of chinook between the hatchery and river mouth. a. 18-24 May, b. 25-31 May.

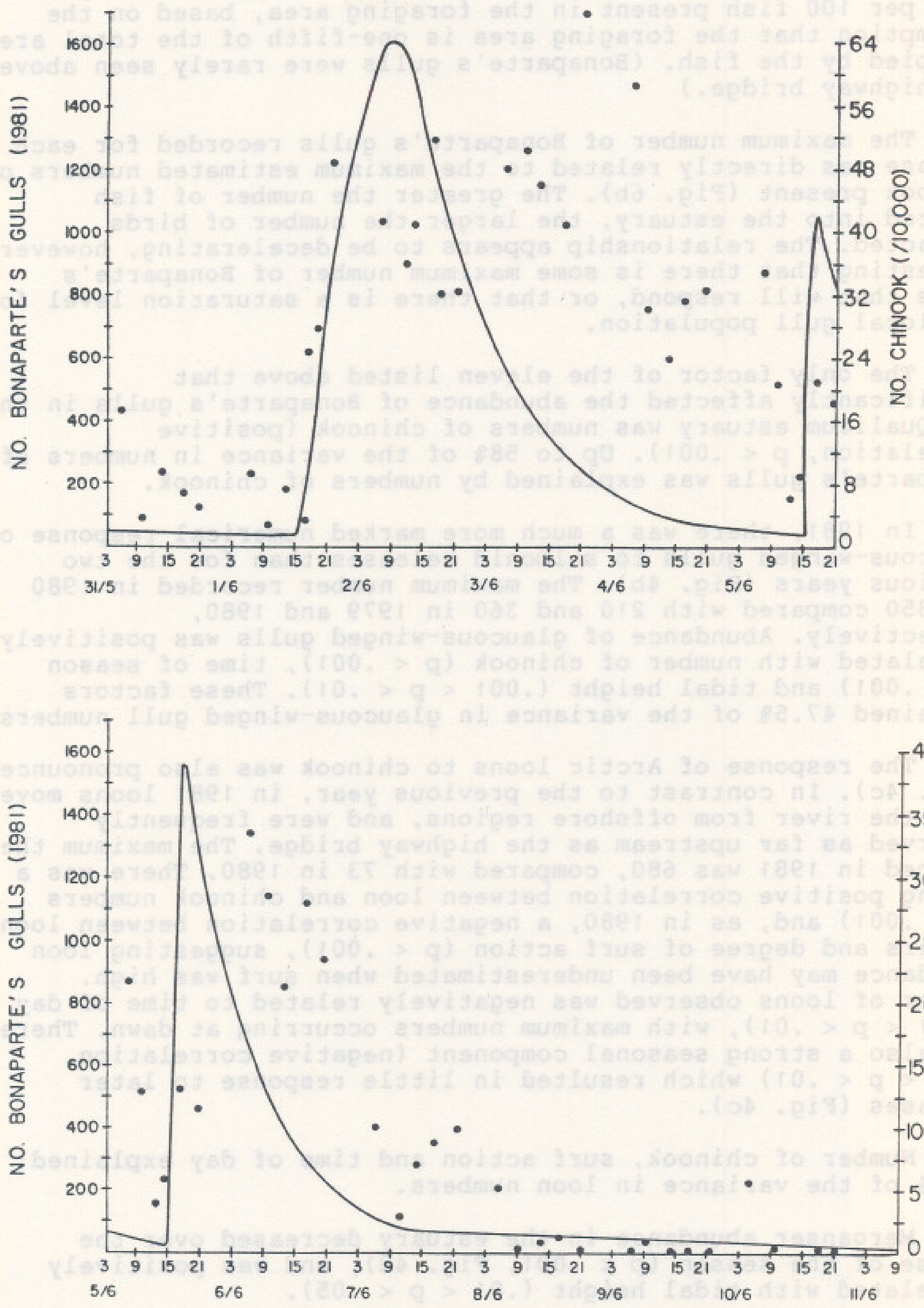


Figure 5 cont. c. 30 May–5 June, d. 5–11 June.

below 400 once the number of chinook reached a level of about 20,000 (Fig. 6a). This represents a ratio of approximately one bird per 100 fish present in the foraging area, based on the assumption that the foraging area is one-fifth of the total area occupied by the fish. (Bonaparte's gulls were rarely seen above the highway bridge.)

The maximum number of Bonaparte's gulls recorded for each release was directly related to the maximum estimated numbers of chinook present (Fig. 6b). The greater the number of fish shunted into the estuary, the larger the number of birds attracted. The relationship appears to be decelerating, however, suggesting that there is some maximum number of Bonaparte's gulls that will respond, or that there is a saturation level for the local gull population.

The only factor of the eleven listed above that significantly affected the abundance of Bonaparte's gulls in the Big Qualicum estuary was numbers of chinook (positive correlation, $p < .001$). Up to 58% of the variance in numbers of Bonaparte's gulls was explained by numbers of chinook.

In 1981, there was a much more marked numerical response of glaucous-winged gulls to salmonid releases than for the two previous years (Fig. 4b). The maximum number recorded in 1980 was 850 compared with 210 and 360 in 1979 and 1980, respectively. Abundance of glaucous-winged gulls was positively correlated with number of chinook ($p < .001$), time of season ($p < .001$) and tidal height ($.001 < p < .01$). These factors explained 47.5% of the variance in glaucous-winged gull numbers.

The response of Arctic loons to chinook was also pronounced (Fig. 4c). In contrast to the previous year, in 1981 loons moved into the river from offshore regions, and were frequently observed as far upstream as the highway bridge. The maximum they reached in 1981 was 680, compared with 73 in 1980. There was a strong positive correlation between loon and chinook numbers ($p < .001$) and, as in 1980, a negative correlation between loon numbers and degree of surf action ($p < .001$), suggesting loon abundance may have been underestimated when surf was high. Number of loons observed was negatively related to time of day ($.001 < p < .01$), with maximum numbers occurring at dawn. There was also a strong seasonal component (negative correlation, $.001 < p < .01$) which resulted in little response to later releases (Fig. 4c).

Number of chinook, surf action and time of day explained 39.1% of the variance in loon numbers.

Merganser abundance in the estuary decreased over the course of the season ($p < .001$, Fig. 4d), and was positively correlated with tidal height ($.01 < p < .05$).

Harlequin ducks were considerably more abundant in 1981

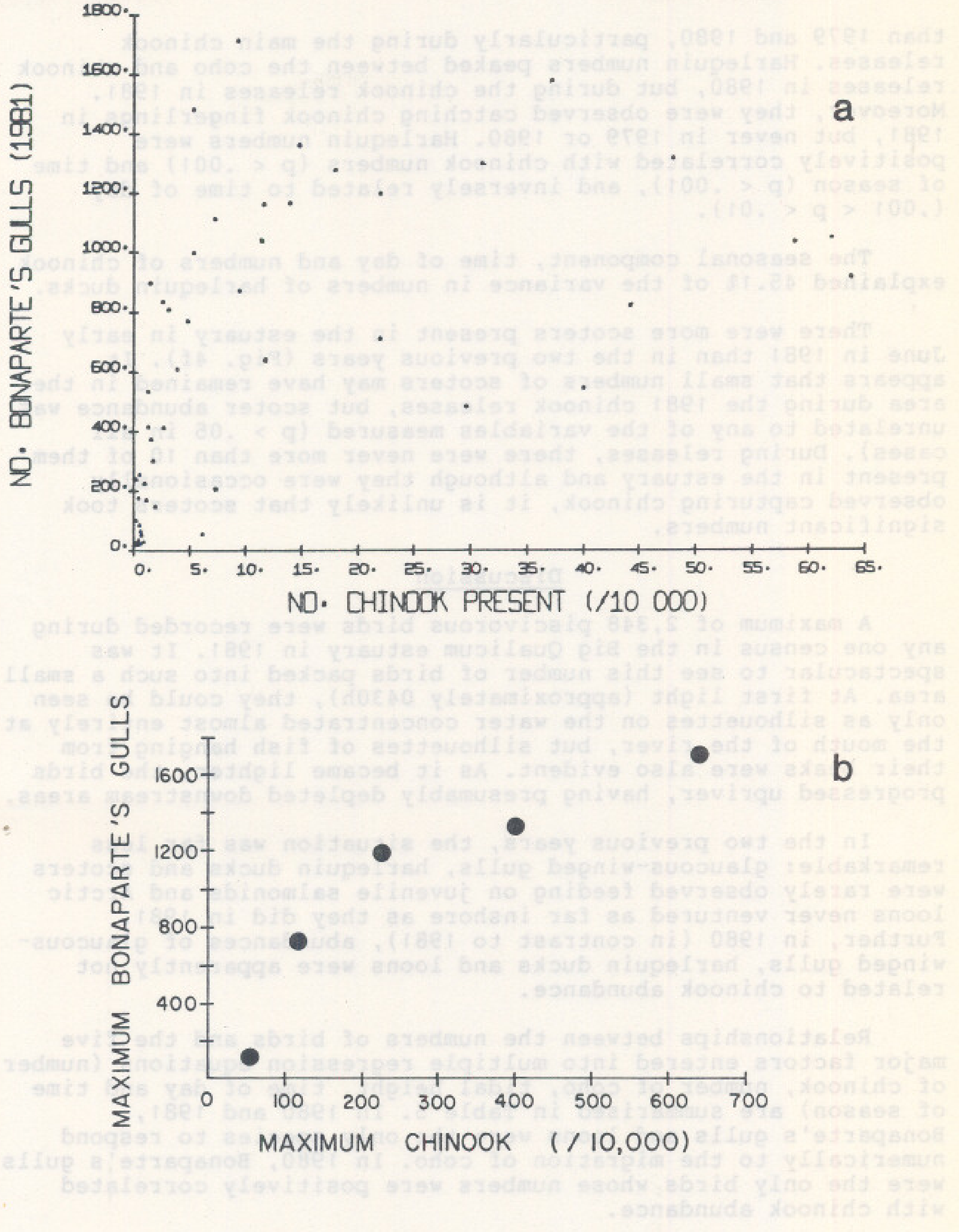


Figure 6. Relationship between numbers of Bonaparte's gulls in the Big Qualicum estuary and the estimated numbers of chinook between the hatchery and river mouth in 1981. a. all numbers recorded from 1–10 June. b. Maximum numbers during each release.

than 1979 and 1980, particularly during the main chinook releases. Harlequin numbers peaked between the coho and chinook releases in 1980, but during the chinook releases in 1981. Moreover, they were observed catching chinook fingerlings in 1981, but never in 1979 or 1980. Harlequin numbers were positively correlated with chinook numbers ($p < .001$) and time of season ($p < .001$), and inversely related to time of day ($.001 < p < .01$).

The seasonal component, time of day and numbers of chinook explained 45.1% of the variance in numbers of harlequin ducks.

There were more scoters present in the estuary in early June in 1981 than in the two previous years (Fig. 4f). It appears that small numbers of scoters may have remained in the area during the 1981 chinook releases, but scoter abundance was unrelated to any of the variables measured ($p > .05$ in all cases). During releases, there were never more than 10 of them present in the estuary and although they were occasionally observed capturing chinook, it is unlikely that scoters took significant numbers.

Discussion

A maximum of 2,348 piscivorous birds were recorded during any one census in the Big Qualicum estuary in 1981. It was spectacular to see this number of birds packed into such a small area. At first light (approximately 0430h), they could be seen only as silhouettes on the water concentrated almost entirely at the mouth of the river, but silhouettes of fish hanging from their beaks were also evident. As it became lighter, the birds progressed upriver, having presumably depleted downstream areas.

In the two previous years, the situation was far less remarkable: glaucous-winged gulls, harlequin ducks and scoters were rarely observed feeding on juvenile salmonids and Arctic loons never ventured as far inshore as they did in 1981. Further, in 1980 (in contrast to 1981), abundances of glaucous-winged gulls, harlequin ducks and loons were apparently not related to chinook abundance.

Relationships between the numbers of birds and the five major factors entered into multiple regression equations (number of chinook, number of coho, tidal height, time of day and time of season) are summarised in Table 5. In 1980 and 1981, Bonaparte's gulls and loons were the only species to respond numerically to the migration of coho. In 1980, Bonaparte's gulls were the only birds whose numbers were positively correlated with chinook abundance.

It is interesting to note that the flocks of Bonaparte's gulls responding to the coho releases were composed mainly of adult birds, whereas those responding to the chinook releases consisted mostly of juveniles. Between May 10 and May 16, 1981,

Table 5. Summary of relationships of abundances of birds to numbers of coho, numbers of chinook, tidal height, time of day, and time of season in the Big Qualicum estuary. "+" indicates a significant positive relationship, "-" indicates a significant negative relationship, and a blank indicates no significant relationship (t-tests at the p = .05 level). The first entry in each column is based on the 1980 data, the second on the 1981 data.

Species	No. Chinook	No. Coho	Tidal Height	Time of Day	Time of Season
Bonap.	+ +	+ +	−		
Glauc.	+		+ +		+ +
Loon	+	+		− −	− −
Merg.			+ +	−	− −
Harl.	+			−	+ +
Scot.					− −

adults made up an average of 91.2% of the flocks. By May 22 to May 28, less than 13% of the gulls present in the estuary were adults.

In 1981, in contrast to the two previous years, glaucous-winged gulls, loons and harlequins showed positive responses to chinook abundance, and reached high numbers during the releases. The exaggerated responses of the birds to the chinook migration in 1981 were probably not entirely due to the nutrient-imbalance problem. The earlier timing of releases may also have enhanced responses, particularly in the case of Arctic loons. In both 1980 and 1981, loon numbers peaked in mid- to late May and declined to very low numbers in early June. The first large release of chinook occurred during peak numbers of loons in 1981, but after most of the migrants had passed through in 1980.

Numbers of mergansers and scoters also showed a strong seasonal decline. It therefore appears that much of the predation by loons, mergansers and scoters could be avoided by delaying the salmonid releases. On the other hand, glaucous-winged gull numbers and harlequin duck numbers increased throughout the season, which suggests that a delay in releases will result in more predation by these species. This is true only if juvenile salmonids are unhealthy. Neither harlequins nor glaucous-winged gulls appeared to be effective predators on small, healthy fish.

Loons, mergansers and harlequins were more likely to be found in the estuary early in the morning, rather than later in the day. Thus, it may be possible to further reduce bird predation by denying access to the salmonids during early morning. It also appears that releases should be geared to tidal height, in order to alleviate predation by mergansers, Bonaparte's gulls and glaucous-winged gulls. However, the positive correlations between bird numbers and tidal heights are probably spurious relationships. Tides are usually high at dawn in May and June in the Big Qualicum area. The negative relationship between Bonaparte's gull numbers and tidal height is considered in more detail in the next section.

5: THE FEEDING RESPONSE

There have been few detailed studies on feeding responses of birds, particularly gulls, to migrating juvenile salmonids. Generalizations about gull predation have often been inferred from limited data comprising only bird counts or small numbers of stomach content samples, without direct observations of feeding behaviour. Such data are insufficient by themselves to reliably estimate impacts of the birds. For example, although there were often large numbers of glaucous-winged gulls present in 1979 and 1980, the years of healthy fish releases, they were rarely seen feeding on juvenile salmonids and their impact in normal years is probably negligible despite their large numbers and potential feeding capacities.

There were two objectives in studying the feeding response:

1. To determine numbers of juvenile coho and chinook taken by Bonaparte's gulls and glaucous-winged gulls in 1979, 1980 and 1981.
2. To determine the role of factors like salmonid density, tidal height, time of day and time of year, in order to infer likely impacts under release schedules other than those observed.

The feeding response was studied only for Bonaparte's gulls and glaucous-winged gulls.

Methods

Several different kinds of observations and experiments on the feeding behaviour of the gulls were carried out. The first was simply to record the numbers of birds feeding in each area of the estuary at each census, and to rank their level of feeding activity (subjectively) on a scale of 1-3: 1-intense feeding, 2-moderate feeding, 3-sporadic feeding or searching. These data were subsequently related through stepwise multiple regressions to factors 1-11 listed in section 4. As in that section, only those variables with significant coefficients (at the p = .05 level, F-tests) are discussed. Significance levels given for (partial) correlation coefficients were determined by t-tests.

The second type of observation was more informative.

Numbers of fish taken by the gulls over specific time intervals were counted. This was particularly easy to do for Bonaparte's gulls, as these birds feed in a tern-like manner: they hover above the water while searching and then make shallow dives, pick up fish in their beaks and swallow them while in the air. As each fish took several seconds to ingest, it was usually possible to identify the species of fish taken, on the basis of its size, shape and colouration. Observations could be made from close range without the need for a blind or other form of camoflague, as the birds were apparently undisturbed by the presence of observers as long as the observors did not make sudden movements.

The river was divided into four or five distinct areas based on average water depths and the regions where the birds concentrated their feeding. Birds feeding in each area were counted immediately prior to each observation. The general procedure then was for one person to count all strikes (dives) made by all birds feeding in one of the areas, whether or not these strikes were successful, and for another person to count both the total number of strikes and the number of successful strikes made by a smaller number of birds within the area. The total number of successful strikes for each area was then obtained by multiplying the ratio of successful strikes for the smaller number of birds by the total number of strikes recorded. Finally, the number of successful strikes for the entire feeding area (see Fig. 1b) was estimated by applying the results from one area to all other feeding areas in proportion to the number of birds feeding in each area at the time, making corrections for different success rates in different areas if necessary. This method of recording feeding activity was feasible in a system such as the Big Qualicum River because the total area over which the birds were feeding was small: generally less than 350 m x 35 m and often as small as 90 m x 35 m.

When feeding activity was intense, successful and unsuccessful strikes were counted over intervals of only five minutes' duration at a time. During each five-minute period, there were up to 650 strikes in total and up to 200 successful strikes within the area under observation. A set of feeding observations usually consisted of at least three such counts made within a half-hour period. More observations were made when variation in success rates was high. When feeding activity was less intense, counts were made for 10-15 minute intervals at a time.

Feeding activity was observed at frequent intervals throughout the day and throughout the period of salmon migration, covering as many different salmonid densities, water depths and times of day as possible. The feeding observations yielded information on the proportion of birds feeding at any given time, the intensity or rate of feeding activity (number of strikes per bird per time interval) and the rate of success. The relationship between these data and each of the independent variables was determined.

When both the tidal height and the salmonid density were low, a third method of quantifying the feeding response was used. This consisted of blocking off sections of the river so that fish were diverted through a passage narrow enough that one person could count all fish migrating down the river over five-minute time intervals. Another person counted the number of fish captured by birds downstream from this point over the same time interval. This method was thought to be reasonably accurate for chinook in riffle areas at very low tides because chinook were unable to hold for long in rapidly flowing water. The method was not useful for coho smolts as they were better able to hold in the current and often swam back upstream.

Another set of experiments was performed shortly after the end of all releases from the hatchery to determine the efficiency of Bonaparte's gulls at low densities of chinook. Known numbers of chinook were released in the river 10-20 m above the main Bonaparte feeding area and the number of fingerlings captured over the next thirty-minute period was recorded. Chinook used in these experiments were "healthy"; that is, they did not have cataracts in their eyes. A set of feeding observations was carried out prior to each release to ensure that there were not significant numbers of chinook still entering the estuary. Releases of 25, 50, 100 and 200 chinook were made.

Finally, feeding activity of individual birds, both Bonaparte's gulls and glaucous-winged gulls was observed. The actions of single birds that were actively feeding were recorded over 30 second intervals for a total period of 5-10 minutes, or until the bird was lost from sight. Few observations of this sort were made because it proved extremely difficult to keep track of one bird amongst a flock of fast-flying, seemingly identical individuals. Most records were obtained during the peak of the blind chinook out-migration period, at which time there appeared to be a considerable amount of waste-feeding occurring, particularly on the part of Bonaparte's gulls. By "waste-feeding", I mean that the gulls were capturing large numbers of chinook that they did not subsequently eat. Observations on individuals enabled an assessment of the extent of this phenomenon.

Extent of waste-feeding was also estimated by observing the relative numbers of captured fish that were eaten compared with the numbers dropped. Each set of observations of this type consisted of records on 20 captured fish. Observations were compared between times when the chinook were abundant and included many semi-blind individuals, and times when chinook numbers were low and most of them appeared to be healthy.

Results

1. Feeding activity

In both 1980 and 1981, the number of Bonaparte's gulls feeding was positively correlated with numbers of chinook ($.001 < p < .01$ for 1980 and $p < .001$ for 1981) and, to a lesser extent, numbers of coho smolts ($.01 < p < .05$ in both years). In 1981, numbers feeding showed a general decrease throughout the day ($.01 < p < .05$) but did not bear an obvious relationship to tidal height ($p > .05$). This contrasts markedly with the data from 1980 when the correlation with time of day was overriden by a strong relationship between feeding and tidal height ($p < .001$). None of the other factors, such as weather, were important to the feeding activity of these gulls ($p > .05$).

In 1980, number of chinook, tidal height and time of day explained 33.2% of the variation in the number of Bonaparte's feeding. Tidal height and time of day explained 25.2% of the variation in numbers of Bonaparte's searching for food. The number of Bonaparte's searching for food was apparently independent of the number of chinook fingerlings present ($p > .05$). In 1981, number of chinook and time of day explained only 11.9% of the variation in numbers of Bonaparte's feeding.

In 1980, the relationship between number of Bonaparte's gulls feeding and tidal height was pronounced: below a tidal height of about 3 m the gulls were feeding; above it, they were not (Fig. 7a). No such relationship was evident in 1981 (Fig. 7b). Because the fish were partially blind in 1981, Bonaparte's gulls were able to feed at all tides and, in fact, there appears to have been an increase in numbers feeding at higher tides. This probably occurred because at dawn when feeding was often the most pronounced, tides were usually high.

There were also major differences between the two years in the areas where the gulls concentrated feeding. In 1980 (and in 1979), at least 90% of the feeding occurred over a 110 m length of river located directly below the highway bridge. This is the most exposed part of the river and also the most shallow. In contrast, in 1981, feeding occurred throughout the estuary to the mouth of the river (Fig. 1b) and often out into the surf zone. The depth of the river apparently did not have as much relevance in this year. In addition, at very low tides a bar formed across the river mouth and effectively blocked off about 85% of the access from the river. This occurred at tides below 0.85 m and facilitated capture by birds when the fish reached this area.

During some counts, depths in the river were monitored in addition to recording tidal heights. Water depths in the river remained constant below tidal heights of about 2.75 m. The approximate maximum and modal depths of the river for tidal heights below 2.75 m are plotted in Fig. 8 for the section of

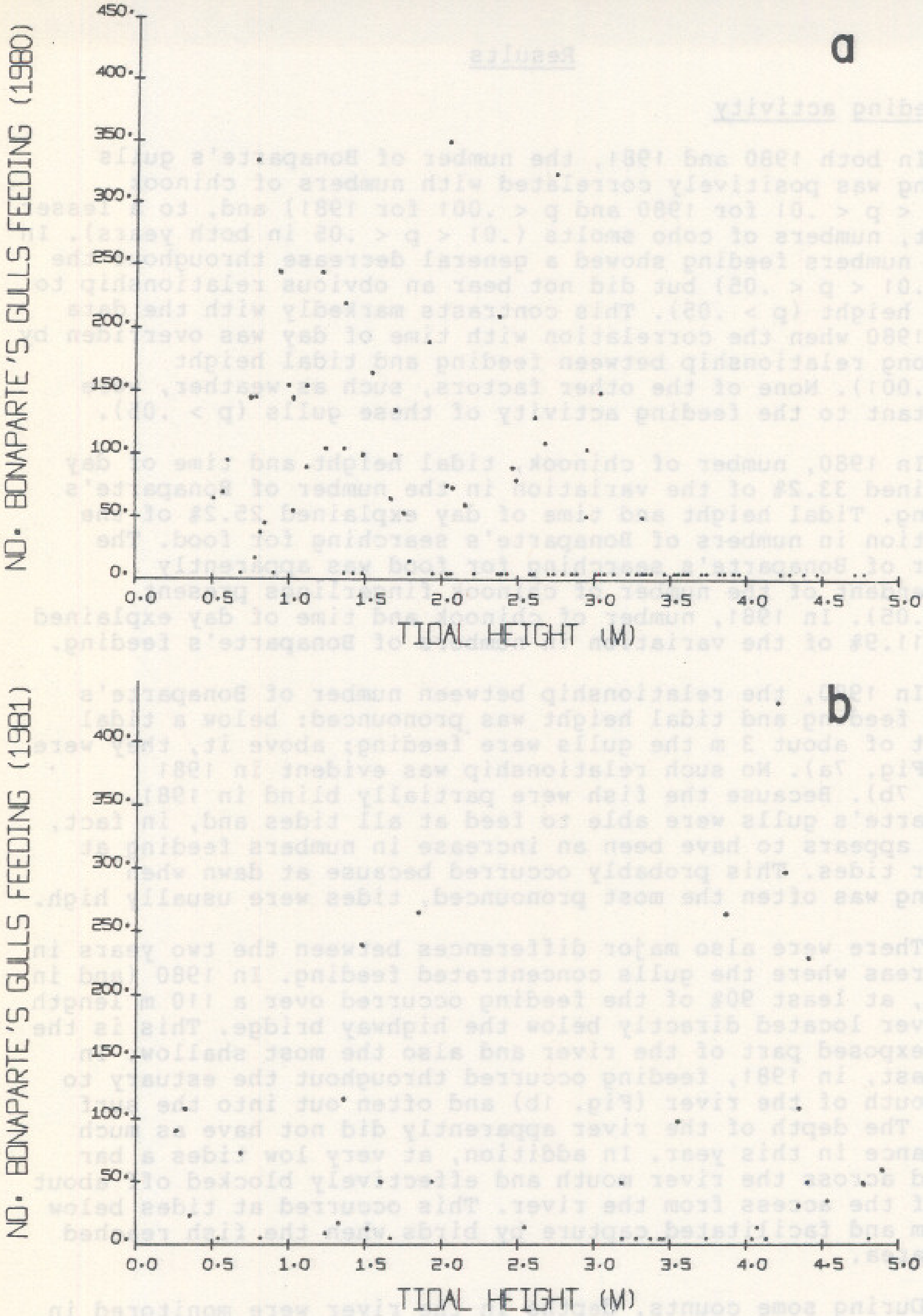


Figure 7. Relationship between numbers of Bonaparte's gulls feeding and the tidal height in the Big Qualicum estuary. a. 1980, b. 1981.

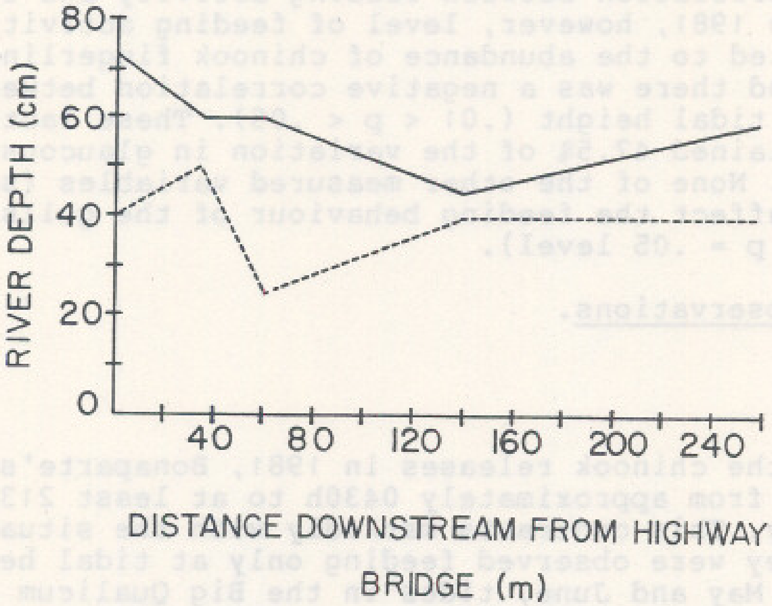


Figure 8. Average (----) and maximum (——) depths of the Big Qualicum River downstream from the highway bridge at tides less than 2.75 m.

river below the highway bridge. It is evident that most of the area over which the birds fed was only about 40-50 cm in depth at low tides. On incoming tides, water depths increased rapidly for tidal heights above 2.75 m and, in 1980, few gulls were feeding once the tide exceeded 3.0 m. This implies that Bonaparte's gulls are ineffective at catching healthy chinook fingerlings in water more than about 80 cm in depth.

The number of glaucous-winged gulls observed feeding in 1980 was always small. For 86% of the 321 counts made, there was no feeding activity by the gulls. For the remaining 14% of the counts, there were usually 2-10 gulls feeding at any time, although larger numbers were searching for food. Glaucous-winged gulls were rarely observed capturing coho smolts or chinook fingerlings and their abundance was only loosely related to the abundance of juvenile salmonids (no significant correlation with either chinook or coho abundance, $p > .05$). There was also no detectable correlation between feeding activity and tidal height ($p > .05$). In 1981, however, level of feeding activity was closely related to the abundance of chinook fingerlings ($p < .001$) and there was a negative correlation between feeding activity and tidal height ($.01 < p < .05$). These factors taken together explained 47.5% of the variation in glaucous-winged gull numbers. None of the other measured variables (section 4) appeared to affect the feeding behaviour of the gulls in either year (at the $p = .05$ level).

2. Feeding observations.

2a. Chinook

During the chinook releases in 1981, Bonaparte's gulls fed continuously from approximately 0430h to at least 2130h, a total of 17 h daily. This contrasts markedly with the situation in 1980 when they were observed feeding only at tidal heights less than 3 m. In May and June, tides in the Big Qualicum area are lower than 3 m for a daily average of about eight hours, and a maximum of 9.5 h. Thus, the length of the feeding period in 1981 was approximately twice as long as that in 1980.

More than 400 five-minute observations of feeding by Bonaparte's gulls were made in 1981. This was sufficient to enable division of the observations into smaller groups for which values of two of the three independent variables (salmonid density, time of day and water depth) were relatively constant. Effects of each independent variable on the proportion of birds' feeding, the rate of attempted strikes and the rate of success were determined for appropriate subsets of data by calculating Kendall rank correlation coefficients.

The proportion of birds feeding in 1981 was positively correlated with chinook density ($p < .001$), negatively correlated with time of day ($.001 < p < .01$) and uncorrelated with water depth ($p > .05$). When data for all chinook densities were considered together, intensity of striking was positively correlated with chinook density ($p < .001$) and uncorrelated with time of day or water depth ($p > .05$). At low chinook densities, there was a negative correlation between water depth and strike intensity ($.001 < p < .01$). The proportion of strikes that were successful was also positively correlated with chinook density ($.001 < p < .01$) and uncorrelated with time of day and water depth ($p > .05$). Strike rates of up to 9.4 strikes per bird per five-minute period were recorded. Capture success was up to 93% of the strikes made.

In the above calculations, estimates of the number of chinook in the entire area below the hatchery were used as indexes of chinook density. This may not have been a good indicator of chinook abundance in the areas where the birds were feeding, particularly at low levels of chinook. It may account, in part, for high variability in success rates at apparently low fish densities (Fig. 9). Higher rates of success may have occurred when schools of fish passed through the feeding areas. At low chinook densities, there was a considerable amount of interference between the birds. Often, five or more birds were observed to dive into the same spot in the water while only one emerged with a fish.

A small number of feeding observations were carried out on Bonaparte's gulls and chinook fingerlings in 1980. In total, 24 five-minute observations were made at different times throughout the migration period. An average of 114.2 successful strikes per five-minute period for all Bonaparte's gulls feeding in the estuary in 1980 was recorded. This is similar to the average obtained in 1981, but the maximum estimated in 1980 (152) was considerably less than the maximum from 1981 (545). In 1980, capture successes of up to 76% of the strikes were recorded (compared with 93% in 1981). The maximum ingestion rate was an average of two fish per minute by one gull for a total of 3.5 minutes.

As Bonaparte feeding was restricted to a smaller area in 1980, it was possible to also record the rate at which the gulls entered and left the feeding area in that year. Over 5-minute time intervals, an average of 161 gulls arrived at the feeding area, and 116 left (based on a total of five counts). This indicates a constant turnover of gulls between the feeding area (just below the highway bridge) and the resting area (near the mouth of the river).

Glaucous-winged gulls were rarely observed capturing chinook fingerlings in 1979 and 1980, but in 1981 they took large numbers, particularly at the peak of the releases. The maximum estimated number of chinook taken by these birds over a five-minute period was 1,848. At the time there were approximately 660 glaucous-winged gulls feeding in the area. The gulls took few fingerlings at high tides, or between releases,

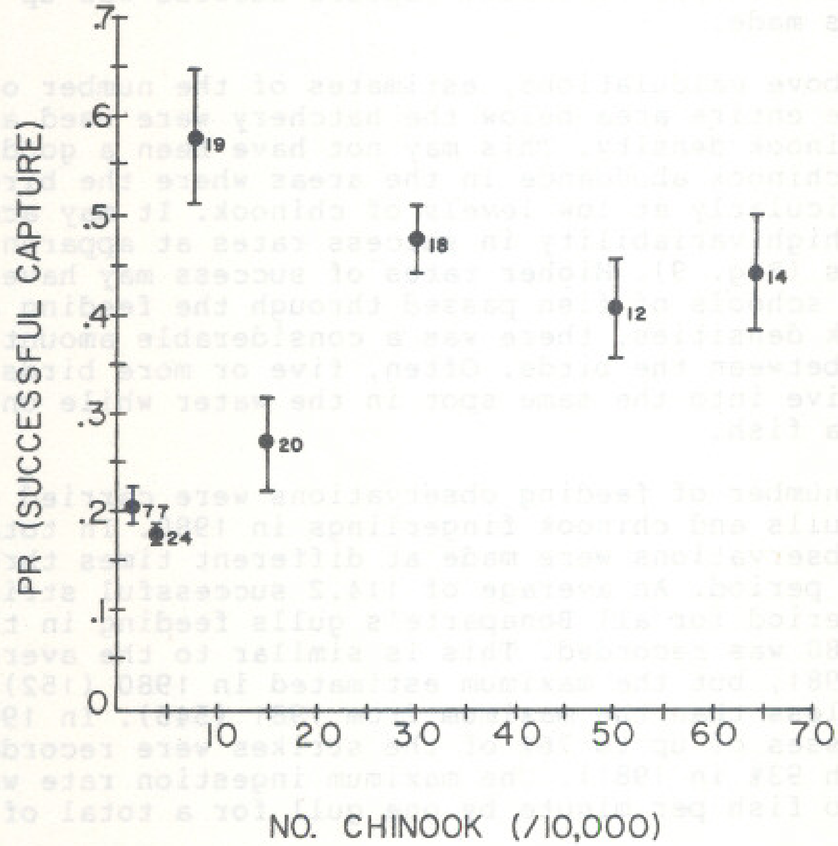


Figure 9. Relationship between the probability that a strike by a Bonaparte's gull will result in the successful capture of a chinook fingerling and the density of the fingerlings. Data are for tides less than 2.75 m only. Vertical bars give standard errors of the mean. Small numbers indicate sample sizes.

or when most of the chinook descending the river were free from cataracts.

2b. Coho smolts

Throughout most of this study, it was difficult to determine whether birds were capturing chinook fingerlings or coho smolts. The most reliable estimates for coho are based on data collected prior to the chinook releases. For the rest of the time, catches were allocated between coho and chinook on the basis of the following information and assumptions. At peak chinook densities, it was assumed that no coho smolts were taken by gulls. This seemed reasonable as chinook were considerably more abundant and appeared to be markedly easier to catch than coho. In addition, it was noted that whereas chinook descended the river at all times of day, coho appeared to congregate under and above the highway bridge until late afternoon when they started to enter the estuary. Between chinook releases, it was assumed that most of the fish taken were coho smolts if gulls were observed capturing larger salmon-shaped fish than usual, and if underwater counts indicated that coho were more numerous than chinook in the estuary.

The maximum success rate recorded for Bonaparte's gulls feeding on coho smolts in 1981 was 33%, considerably lower than the maximum rate recorded for chinook fingerlings (93%). It appeared that coho smolts were dropped more frequently than chinook. The maximum estimated number of successful strikes made by all Bonaparte's gulls feeding on coho in the estuary was 63 per five-minute period (compared with a maximum of 545 for chinook fingerlings).

In 1980, only eight five-minute observations of feeding by Bonaparte's gulls on coho smolts were made. An average of 7.4 smolts were captured each five-minute period.

Bonaparte's gulls were never observed capturing coho at tides above 3.0 m. There was a strong correlation between time of day and number of coho taken ($.001 < p < .01$): predation on coho was highest in late afternoon and early evening.

Glaucous-winged gulls were rarely seen catching coho smolts in any of the three years of this study.

3. Chinook diversion experiments

The purpose of the chinook diversion experiments was to determine the efficiency of Bonaparte's gulls as predators at low chinook densities. Accordingly, the experiments were carried out close to the beginning or end of releases from the hatchery. Figure 10a depicts the numbers of chinook that were counted passing through riffle areas in the river and numbers subsequently captured by Bonaparte's gulls downstream. The range of data collected is limited because it was not possible to

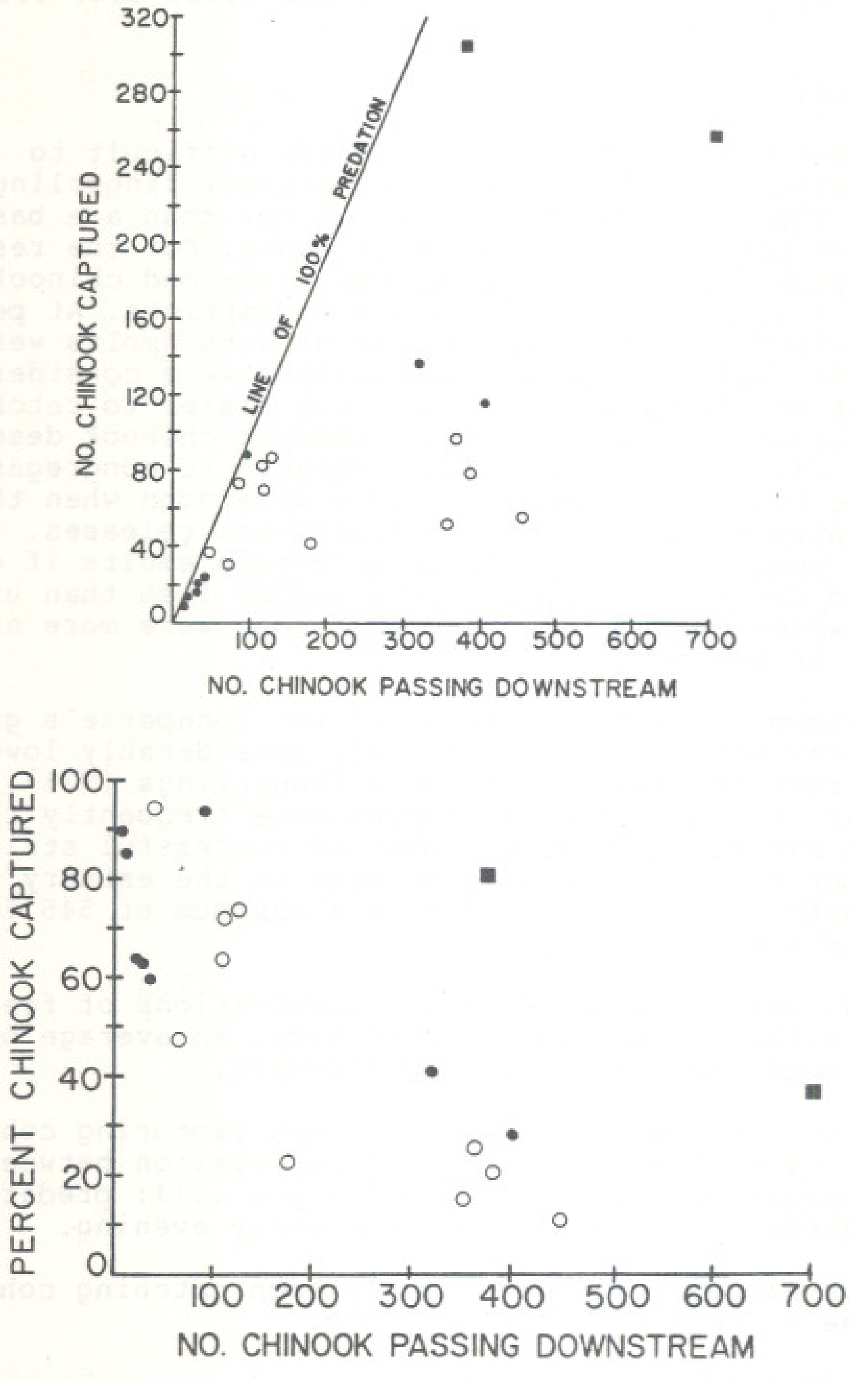


Figure 10. Numbers (a) and percentages (b) of chinook passing downstream over five-minute time intervals, that were subsequently captured by Bonaparte's gulls. Different symbols are used depending on the numbers of birds responding. ○ 20–35 birds, • 45–80 birds, ■ 180–200 birds.

control either the number of fish migrating downstream or the number of birds responding to the migration. Numbers of birds recorded feeding at each count fall into three groups: 20-35, 45-80 and 180-200 birds. Only two observations were made for flocks of 180-200 birds. For the other two groups, number of fish captured was a negatively accelerating function of numbers present. Thus, the percentage of fish captured declined as their density increased (Fig. 10b). At low densities, percent predation was extremely high. Up to 95% of the fish that were channeled through the riffle areas were subsequently captured by Bonaparte's gulls.

4. Release experiments

Only 14-32 Bonaparte's gulls responded to releases of (small) known numbers of chinook into the Big Qualicum River. (By waiting until the end of all hatchery releases to ensure that few other chinook were present in the estuary, it also happened that there were few Bonaparte's gulls present.) Figure 11 shows the numbers and percentages of chinook taken by these gulls for releases of 25, 50, 100 and 200 fish. Over the range of densities tested, number of chinook captured was a linear function of number released. Percentages of fish taken at each release were similar. An average of 64% of the chinook was captured by gulls.

5. Observations on individual birds / Extent of waste feeding

Eighteen individual Bonaparte's gulls were observed for a total of 75 minutes at times when semi-blind chinook made up a large proportion of the fish migrating downstream. These 18 birds captured a total of 142 chinook, of which 124 were dropped and 18 were eaten. Thus, they ate only 12.7% of the fish captured. On average, each gull ate one fish and dropped 6.9 fish over a time period of four minutes and ten seconds. Average handling time for each fish eaten was 15.5 seconds.

In contrast, when most of the 1981 chinook descending the river were healthy (as determined from underwater observations), observations on seven separate groups each consisting of 20 Bonaparte's gulls showed that they ingested an average of 90.0% of the 140 chinook captured. Proportions of captured fish eaten were significantly different from each other by the X^2 test ($p < .01$) for the two sets of data.

Thirteen individual glaucous-winged gulls were observed feeding on partially-blind chinook for a total of 60 minutes. They caught an average of 3.0 chinook each 4.5 minutes. They ingested 71.8% of the fish captured. Their rate of capturing fish was, therefore, lower than that for Bonaparte's gulls, but they ate appreciably more of the chinook caught. One glaucous-winged gull was observed to capture and ingest six chinook in slightly less than four minutes. Average handling time by glaucous-winged gulls was 6.3 seconds, less than half the time

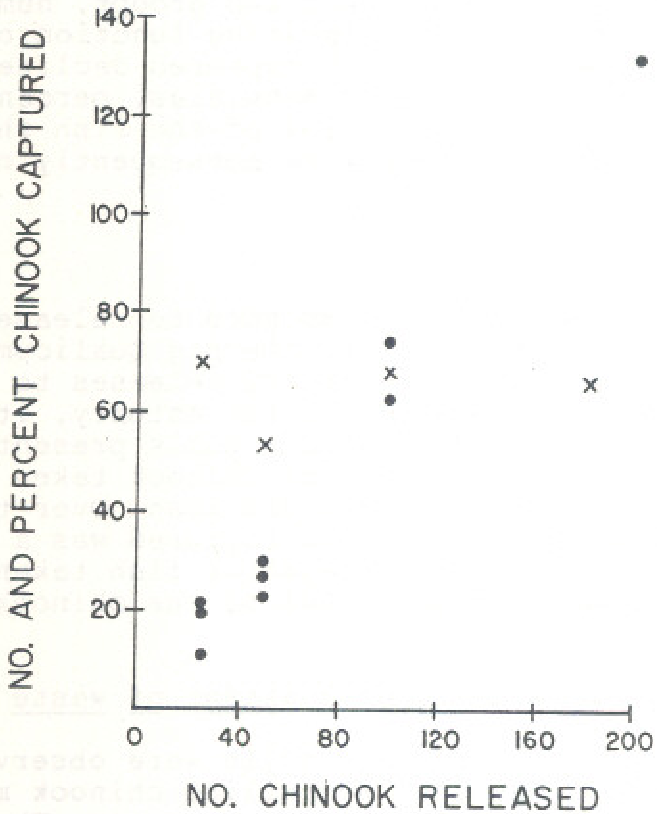


Figure 11. Numbers (•) and percentages (×) of chinook captured by Bonaparte 's gulls over 30 minute periods following releases of 25, 50, 100 and 200 chinook in the river upstream from the birds' feeding area.

taken by Bonaparte's gulls.

When most of the chinook descending the river were healthy, glaucous-winged gulls were rarely observed capturing them. Therefore, it is not possible to determine whether the proportion of captured semi-blind chinook eaten is representative for healthy fish.

Discussion

Differences between 1980 and 1981 in feeding behaviour of both Bonaparte's gulls and glaucous-winged gulls are probably almost entirely attributable to differences in the health of the chinook. The most overt symptom of the nutrient-deficiency problem in 1981 was impaired sight, but it is possible that there were also other effects as the fingerlings were extremely easy to catch. Even humans were often able to pick the semi-blind chinook out of the water between two fingers. One would therefore expect that capture would have been particularly easy for birds, including glaucous-winged gulls which are generally too clumsy to catch fast-moving, small fish.

Owing to their impaired sight, the chinook had little refuge from birds even at high tide. Although Bonaparte's gulls appeared to be capable only of shallow water dives of about 30 cm, depth of the water had little effect on their feeding activity or success rate. In 1981, chinook were distributed throughout the water column, particularly when numbers were high and a large proportion had impaired vision. The partially-blind fish were either unable to see the river bed or the birds hovering above the surface, or both. They did not seem to dive for the bottom when birds attacked and often did not react to a diver floating above them. In this case, the only effect of increased water depths was to dilute the density of fish. This acted to reduce capture successes for glaucous-winged gulls, but did not noticeably depress success rates by Bonaparte's gulls.

On the basis of the limited amount of data collected on feeding by Bonaparte's gulls in 1980, it does not appear that feeding rates or success rates differed substantially for the two years, except at water depths greater than 80 cm. In normal years, Bonaparte's gulls are able to feed effectively on chinook fingerlings only at water depths less than 80 cm.

The chinook diversion experiments and the release experiments both indicate that Bonaparte's gulls are extremely efficient predators at low chinook densities. The maximum of 95% predation obtained in the diversion experiments could be a slight over-estimate. Small numbers of chinook may have been able to squeeze through gaps in the screens used to channel fish into counting areas. It is unlikely that these numbers were high, however, as screens were set diagonally with the current. Also, numbers of fish passing through the screens were checked periodically and there were never more than 4-5 counted each five-minute period.

Predation rates recorded for the release experiments were more likely to have been under-estimated. As the chinook selected for these experiments were all free from cataracts, they were able to hold in the riffles and some of them may have swum upstream to areas inaccessible to Bonaparte's gulls.

When the chinook migrating downstream were healthy, or when they were present in low numbers, Bonaparte's gulls ingested the majority of the fish they captured. When chinook were abundant and had impaired vision, there appeared to be a considerable amount of waste-feeding. Although 97.3% of the fish captured under these conditions were rejected by the birds, it is difficult to estimate the actual number of fish killed and not eaten. A fish rejected by one bird could have been subsequently captured and eaten by another bird. It was noted that fish that did not move once they had been captured were almost invariably rejected by Bonaparte's gulls, but were usually ingested by glaucous-winged gulls.

In summary, Bonaparte's gulls were found to be efficient predators on chinook fingerlings in water less than 80 cm in depth, even when fingerlings were present at very low densities. Glaucous-winged gulls were inefficient predators on juvenile chinook under all conditions observed, except when the chinook had severely impaired vision.

6: IMPACT ON JUVENILE COHO AND CHINOOK

The data collected in 1981 were sufficient to allow reasonable estimates of the numbers of juvenile coho and chinook salmon taken by Bonaparte's gulls and glaucous-winged gulls in that year. Unfortunately, because of the nutrient-imbalance problem, these data could not be used directly to obtain similar estimates for 1979 and 1980. Estimates for the latter two years are, therefore, somewhat less reliable but give an indication of the potential these birds have for reducing overall survival rates of the two species of salmonids.

For all three years, impacts of the other species of birds present in the study area were estimated from information on body weights and feeding rates obtained from the literature.

Methods

1. Estimates based on feeding observations

Estimates based on feeding observations were calculated in 1981 for both Bonaparte's gulls and glaucous-winged gulls and in 1979 and 1980 for Bonaparte's gulls only. In 1981, mean numbers of successful strikes for each set of 3-6 five-minute gull feeding observations were used to estimate the number of fish taken during observation periods. Linear interpolations were made between successive records to estimate numbers of fish taken during times when feeding rates were not recorded. The average of two adjacent sets of feeding observations was multiplied by the number of five-minute intervals between the observations. These numbers were then added together to give the estimated daily impact, the impact for each separate release, and the total impact for the year.

In 1979 and 1980, records of water depths at which the gulls were feeding were used to determine the tidal height at which feeding by Bonaparte's gulls effectively ceased. The numbers of hours that tides were below 2.75 and 3.0 m were calculated for each day of release. It was then assumed that average numbers of successful strikes per five-minute period obtained from the 1980 feeding observations (114.2 for chinook and 7.4 for coho) were applicable for tides below 2.75 m and half of this value was applicable for tides between 2.75 and 3.0 m. Each daily estimate thus obtained was summed to give a total estimate for each release.

2. Estimates based on body weights and feeding rates

Data from the literature on body weights, daily food intake as a percentage of body weight, and diet composition were used to obtain independent estimates of the numbers of coho and chinook taken by Bonaparte's gulls and glaucous-winged gulls, and to estimate consumption by loons, mergansers, harlequins and scoters. Daily food intake in grams was converted to appropriate numbers of chinook and coho smolts and multiplied by numbers of birds present in the estuary for each day of release. An average weight of 5 g was used for chinook and 17.5 g for coho. Two different measures of numbers of birds feeding on the fish were used: an "average" and a "maximum". For all estimates except those for gulls feeding on chinook in 1979 and 1980 and gulls feeding on coho in all three years, average numbers of each species were calculated from all daily records, and maximum numbers from records taken prior to 1700h. Maximum numbers beyond 1700h were not considered as it is likely that any new birds arriving after this time would already have done most of their feeding. For gulls feeding on chinook in 1979 and 1980 and gulls feeding on coho in all three years, average and maximum numbers were calculated only from records taken at tides less than 3.0 m. (The data showed a pronounced effect of tidal height on gull feeding for both salmonid species in all years, with the exception of the chinook in 1981.)

Bird weights used were averages of variable numbers of specimens recorded by Bellrose (1976) for mergansers and harlequin ducks, Robertson (1975) for glaucous-winged gulls, and Robertson (1975) and Palmer (1962) for Arctic loons. The average weight of Bonaparte's gulls was calculated from specimens collected during this study and specimens at the Provincial Museum, Victoria, British Columbia. The weight of scoters was assumed to be similar to that for common murre (Uria aalge), estimated by Robertson (1975).

Average daily food intake was considerably more difficult to estimate. As birds have very high metabolic rates, it is not possible to infer daily food intake from stomach contents at one point in time. As an example of the rate at which birds can digest fish, Ward (1914) recorded that a previously starved black-headed gull (L. ridibundis) completely digested a 12.7 cm sprat in less than 3 h. Collinge (1924-1927, cited by Harris 1965) stated that birds digest most food within 3.5 h.

Data obtained from the literature suggest that daily ingestion rates by birds can range from 18% of body weight to twice body weight. Beach (1936) stated that " active fish-eating birds can actively eat twice their own weight in fish each day ". White (1936, 1939), Elson (1962) and Alexander (1979) felt that a daily rate of food intake of 33% of body weight was reasonable for mergansers. Salyer and Lagler (1940) and White (1957) estimated that mergansers eat 33-50% of their body weight per day. Spaans (1971) showed that herring gulls required 18% of their body weight per day when fed on herring, but Harris (1965) recorded a captive adult herring gull of 800 g eating 429 g of fish in 24 h (54% of body weight). Robertson (1975) assumed a standard of 20% of body weight for large piscivorous birds. Tuck and Squires (1955) used a value of 25% for the common murre.

For mergansers, the most generally accepted estimate seems to be that of 33-50% of body weight. This estimate cannot necessarily be applied to all other species as the rate of metabolism is comparatively greater in smaller birds (e.g. King and Farner 1961, Lasiewski and Dawson 1967). Using Lasiewski and Dawson's equation for metabolic rates of non-passerine birds, metabolic rates per gram of body weight for glaucous-winged gulls and Bonaparte's gulls should be about 1.09 and 1.73, respectively, of that for mergansers. However, as values from the literature do not indicate a similar trend in rate of food intake, particularly for larger gulls, estimates of fish consumption that were less than 50% of body weight were generally used. Slightly higher consumption rates of chinook were assumed in 1981 than in the previous two years, due to their relative ease of capture.

For the same reason, it was assumed that the proportion of the diet made up by chinook fingerlings was higher in 1981 than in 1979 or 1980. The values used were guesses based on cursory observations and/or known feeding habits. Harlequins and scoters were assigned low values in 1979 and 1980 as the diets of both species usually consist primarily of crustaceans, molluscs and insects (Cottam 1939, Guiget 1967, Ainley and Sanger 1979). Cottam (1939) stated that fish usually comprised only about 2% of the diet of harlequins. However, it seemed reasonable that this number would be somewhat larger when small fish are extremely abundant.

Glaucous-winged gulls were assumed to derive only a small proportion of their dietary requirements from juvenile salmonids in normal years, as they were rarely seen catching coho or chinook. In 1981, the data suggests that their diet was composed entirely of chinook during the releases and partially of chinook between releases.

Bird weights, consumption rates, and diet compositions used to calculate numbers of chinook and coho eaten are summarized in Table 6. Estimates for mergansers were supplied by Chris Wood (pers. comm.) who carried out a more intensive study of mergansers on the Big Qualicum River in 1980 and 1981.

Table 6. Summary of data used to calculate the number of chinook and coho consumed by piscivorous birds in the Big Qualicum River in 1979, 1980 and 1981. See text for species abbreviations.

Species	Average body wt (g)	Prop. wt consumed per day '79+'80	Prop. wt consumed per day '81	Prop. diet made up by chin. during chin. release '79+'80	Prop. diet made up by chin. during chin. release '81	Prop. diet made up by coho during coho release '79+'80+'81
Bonap.	200	0.50	0.50	1.00	1.00	0.50
Glauc.	1,075	0.20	0.33	0.05	0.80	0.05
Loon	2,500	0.20	0.33	0.50	0.75	0.50
Merg.	1,450	0.50	0.50	0.80	0.80	0.20
Harl.	600	0.33	0.50	0.10	0.50	0.10
Scot.	1,045	0.33	0.50	0.10	0.50	0.10

Results and Discussion

a. Chinook

Estimates of the numbers of chinook taken by the major piscivorous birds in the Big Qualicum River in 1979, 1980 and 1981 are summarized in Tables 7, 8 and 9, respectively. The bird

Table 7. Estimated number of juvenile chinook taken by piscivorous birds in the Big Qualicum River in 1979. See text for definitions of average and maximum, and for species abbreviations.

Species	Feeding Observations	Average	Maximum
Bonap.	215,800	161,900	210,400
Glauc.		1,700	2,700
Loon		?	?
Merg.		(56,300)	(56,300)
Harl.		1,300	3,100
Scot		< 50	< 50
Total		> 221,200	> 272,500
Total as % of release		> 8.71	> 10.73

species considered were Bonaparte's gulls (Bonap.), glaucous-winged gulls (glauc.), Arctic loons (loons), common mergansers (merg.), harlequin ducks (harl.) and three species of scoters: common scoters, surf scoters and white-winged scoters (scot.). The category of glaucous-winged gulls includes all of the larger gulls and the Arctic loons include small numbers of common loons and grebes. Estimates for mergansers were supplied by Chris Wood.

The higher numbers estimated for 1980 (Table 8), compared with 1979 (Table 7), are the result of two factors: a slightly longer length of release in 1980 (26 days compared with 21 days), and the fact that the area counted in 1980 was larger and included more species and more members of each species. A total of 300,000 juvenile chinook or 10-12% of the release appears to be a reasonable estimate of the numbers taken by piscivorous birds in the Big Qualicum estuary in normal years.

The differences between 1981 (Table 9) and the two previous years are the result of two different factors: the nutrient-

Table 8. Estimated number of juvenile chinook taken by piscivorous birds in the Big Qualicum River in 1980. See text for definitions of average and maximum, and for species abbreviations.

Species	Feeding Observations	Average	Maximum
Bonap.	267,900	240,000	289,900
Glauc.		2,600	4,000
Loon		600	1,400
Merg.		(56,000)	(56,000)
Harl.		1,600	3,000
Scot.		< 50	< 50
Total		300,900	354,200
Total as % of release		10.39	12.23

Table 9. Estimated number of juvenile chinook taken by piscivorous birds in the Big Qualicum River in 1981. See text for definitions of average and maximum, and for species abbreviations.

Species	Feeding Observations	Average	Maximum
Bonap.	214,200	234,200	315,200
Glauc.	301,800	351,000	461,000
Loon		198,600	362,500
Merg.		(20,000)	(27,000)
Harl.		47,500	80,500
Scot.		5,200	8,200
Total		856,500	1 260,400
Total as % of release		21.52	31.67

deficiency problem, and the fact that releases began a few weeks earlier in 1981. The considerably larger numbers of chinook taken by loons, mergansers, harlequins and scoters in 1981, compared with 1980, cannot be attributed entirely to the vision problem of 1981. For example, the sum of maximum daily numbers of loons recorded in the area during releases was only 28 in 1980, compared with 2,900 in 1981. Corresponding sums for harlequin ducks were 741 and 2,684, and for scoters 11 and 157. Although there were slightly higher numbers of mergansers present in 1981, their impact was offset by the shorter duration of the releases in that year.

About 1,000,000 of the 3,980,000 chinook (almost 25%) released in 1981 were taken by piscivorous birds in the Big Qualicum estuary. The area covered represents only the first 2 km of the fishes' migration and so does not include predation by birds in near-shore regions. It also excludes predation by other piscivorous species in the area. Other potential predators on chinook within the estuary include the freshwater sculpins (Cottus sp.), the marine staghorn sculpin (Leptocottus armatus), larger salmonids, marine mammals and the spiny dogfish (Squalus aconthias). Few marine mammals were counted near the mouth of the river, but dogfish were abundant. Many sport fishermen camped near the mouth of the river claimed to be continually snagging dogfish on their lines. Dogfish were frequently observed as far upstream as the highway bridge and on one occasion, eight were seen at once in water where visibility was only about 5 m. They were also occasionally found stranded on the shore.

For Bonaparte's gulls in each year and glaucous-winged gulls in 1981, the most reliable estimates of numbers of chinook taken are those based on feeding observations. Feeding observation estimates for Bonaparte's gulls in 1981 (Table 9) are less than those for 1979 and 1980 (Tables 7 and 8) despite the blindness of the fish and the larger aggregation response by the gulls. This result is due to the fact that in 1981 there were only about 12 days when chinook were abundant in the estuary, compared to 21 and 26 days, respectively, in 1979 and 1980. This suggests that the amount of gull predation can probably be reduced considerably if fingerlings leave the estuary quickly.

Percent predation on chinook by both Bonaparte's gulls and glaucous-winged gulls in 1981 was, in fact, lower for forced releases than passive releases (Table 10). Although one would expect percent predation to be lower for larger releases due to finite limits on both number of birds responding to a release and amount each bird can consume, percent predation was lower for the June 5 forced release of 450,000 fish than for the May 25 passive release of 2,100,000 fish. The percentage of the June 5 forced release taken was also lower than that for the larger June 1 forced release of 1,100,000 fish. This is probably because the bulk of the fish left the hatchery in less than 3 h on June 5 compared to 22 h on June 1.

Table 10. Percentage of each release of juvenile chinook consumed by Bonaparte's gulls and glaucous-winged gulls in 1981.

Date release begun	May 19	May 25	June 1	June 5
Size of release	250,000	2,100,000	1,100,000	450,000
Type of release	Passive	Passive	Forced	Forced
% taken by Bonap.	9.83	4.86	5.64	3.68
% taken by glauc	23.91	7.50	5.34	5.01
Total % taken	33.74	12.36	10.98	8.69

b. Coho

Estimates of numbers of coho smolts taken by Bonaparte's gulls, glaucous-winged gulls, loons, mergansers, harlequin ducks and scoters are summarized in Tables 11, 12 and 13 for 1979, 1980 and 1981, respectively. Estimates for mergansers are based on data supplied by Chris Wood (pers. comm.).

In 1981, there were considerably more coho released (1,476,300) than in 1980 (759,200), yet percentage predation in the two years was quite similar. Almost twice as many fish were taken in 1981, probably because the main release in this year began about a week earlier than in 1980. At that time of the season, loons and mergansers were abundant in the Big Qualicum area.

The most reliable estimate in Tables 11-13 is the estimate based on feeding observations for Bonaparte's gulls in 1981. This number is lower than the other two estimates for Bonaparte's gulls for the same year, and the estimates based on feeding observations in the other two years. These latter numbers probably over-estimate predation by Bonaparte's gulls. It is likely that coho smolts constitute a smaller proportion of the diet of Bonaparte's gulls than originally assumed (Table 6).

The amount of predation by piscivorous birds on coho smolts was considerably lower than that on chinook fingerlings for all three years of the study. A predation rate of about 2-4% of the total migration of coho smolts was recorded. This can probably

Table 11. Estimated number of juvenile coho taken by piscivorous birds in the Big Qualicum River in 1979. See text for definitions of average and maximum, and for species abbreviations.

Species	Feeding Observations	Average	Maximum
Bonap.	8,000	4,200	7,300
Glauc.		300	500
Loon		?	?
Merg.			
Harl.		500	900
Scot.		10	40
Total		>5,000	>8,700
Total as % of release		> 0.82	> 1.42

Table 12. Estimated number of juvenile coho taken by piscivorous birds in the Big Qualicum River in 1980. See text for definitions of average and maximum, and for species abbreviations.

Species	Feeding Observations	Average	Maximum
Bonap.	12,000	7,000	8,200
Glauc.		400	700
Loon		3,800	7,300
Merg.		25,300	25,300
Harl.		400	800
Scot.		> 50	> 50
Total		36,900	42,300
Total as % of release		4.92	5.63

be considered to be of little consequence to the overall survival of coho.

Table 13. Estimated number of juvenile coho taken by piscivorous birds in the Big Qualicum River in 1981. See text for definitions of average and maximum, and for species abbreviations.

Species	Feeding Observations	Average	Maximum
Bonap.	4,100	8,500	11,500
Glauc.		1,300	1,500
Loon		9,200	22,800
Merg.		22,000	28,000
Harl.		700	1,100
Scot.		300	400
Total		42,100	65,300
Total as % of release		2.85	4.42

7: BIRD PREDATION IN THE CAPILANO RIVER

A small study of bird predation in the Capilano River, B. C. was carried out for two reasons: to obtain more data on aggregation and feeding responses of birds to healthy fish, and to determine whether predation is generally such a serious problem as that found in the Big Qualicum River. The Capilano system was chosen because it was the only hatchery in the area still releasing chinook and coho after the end of the Big Qualicum releases, and because these fish were not affected by the nutrient-imbalance problem.

The Capilano hatchery is located 5 km from the mouth of the Capilano River in Vancouver. It began operation in 1971 and now produces about 1.5 million chinook fingerlings, 500,000 coho smolts and 20,000 steelhead smolts annually. Fish are reared under similar conditions to those in the Big Qualicum hatchery, except that the water temperatures in Capilano River are about 5-7 C lower than in Qualicum River at the time of the fish releases. Capilano chinook salmon were originally transplants from the Big Qualicum system.

Methods

The numerical response of the birds at the mouth of the Capilano to a late release of approximately 360,000 chinook fingerlings and 36,000 coho smolts was monitored. The area counted extended from the Park Royal bridge to approximately 500 m off the mouth of the river, west towards the Lions' Gate bridge and south towards Stanley Park. Although parts of the river upstream from the Park Royal bridge were checked periodically, little additional bird activity was observed.

The fish were released from the hatchery on June 18 between 1500 and 1600 h. Birds were censused daily at low tide on May 31, June 9, 15 and 16, then from dawn to dusk every 3-5 hours from June 17 to June 20, and then once daily at low tide from June 21 to June 26. Altogether, ten complete counts were made prior to the release to obtain the baseline numbers of birds present. A total of 19 hours of five-minute gull feeding observations were performed using the methods outlined in section 5. One hour of observations was carried out before the release.

Results

The most common species present was the glaucous-winged gull, whose numbers exceeded 300 on several occasions and were rarely lower than 50. The next most common species was the harlequin duck. Mergansers, cormorants, murrelets and mallard ducks were frequently present but usually no more than 10 of each were seen at one time. One or two great blue herons were also usually observed, pigeon guillemots were seen occasionally, Canada geese and horned grebes were rare and one green heron was sighted twice. Bonaparte's gulls were absent throughout.

There was no apparent aggregation response by any bird species present. Figure 12 shows the abundance of glaucous-winged gulls between May 31 and June 26. Although there appears to have been a slight increase in numbers of gulls just following the release, this probably does not represent a response to the release as it was estimated that the fish would take at least 2-4 hours to travel the 5 km to the river mouth. In any case, the increase was not maintained and there was no detectable increase in feeding activity at that time. During 18 hours of feeding observations after the release, only one gull was observed catching a smolt. During many additional hours of cursory observations, only one additional capture by a gull was recorded. On occasion, other bird species such as pigeon guillemots, cormorants, and murrellets were observed feeding on smolts. These species were present in such low numbers that their possible impact was considered insignificant.

Discussion

The reason for the absence of Bonaparte's gulls at the mouth of the Capilano River is not clear. Counts in the Qualicum area in 1979 and 1980 indicate that there are still significant numbers of juvenile Bonaparte's gulls in mid- to late June. It is possible that these gulls simply do not frequent areas close to cities. Weber (1972) sighted only one Bonaparte's gull once in his study of the birds in Vancouver City. Records from the Provincial Museum of bird sightings in Vancouver also indicate that this species is rare in the area. This discrepancy between

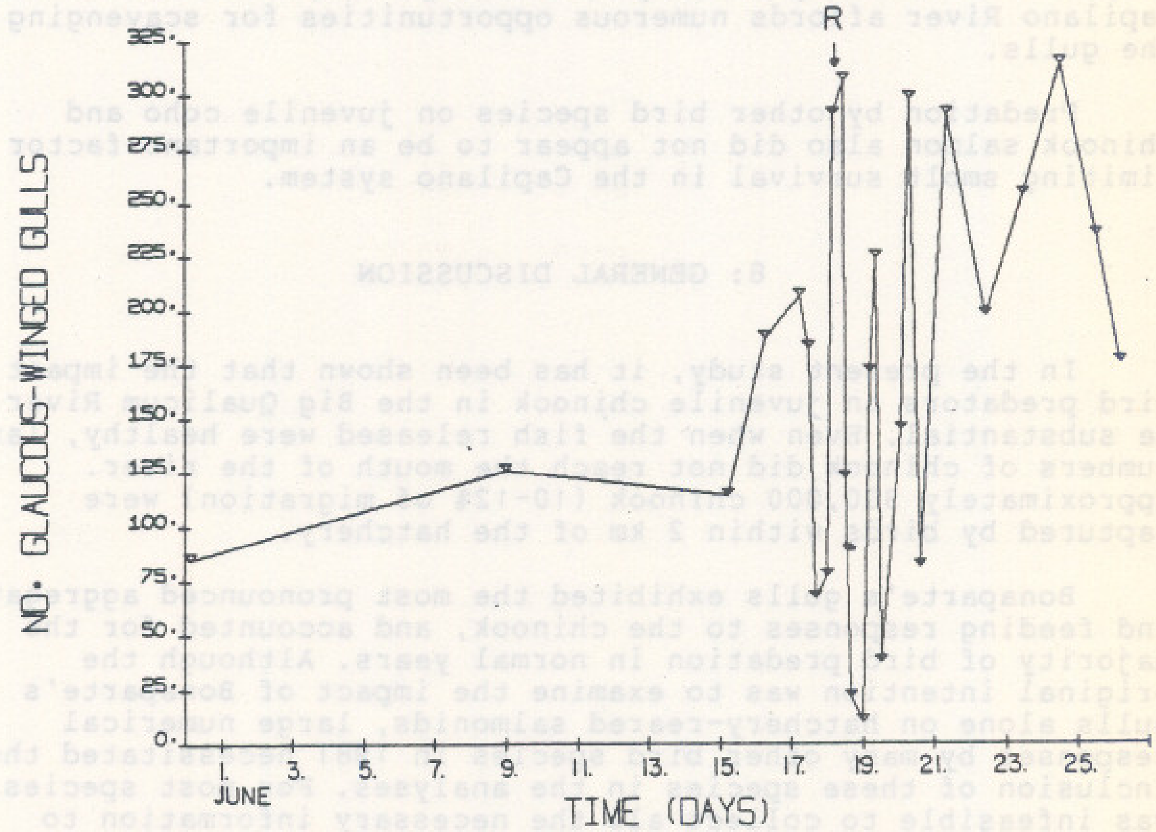


Figure 12. Numbers of glaucous-winged gulls recorded at the mouth of the Capilano River from 31 May to 26 June 1981. "R" indicates the time of the chinook and coho release.

the two study sites made it impossible to make further conclusions about the possible impact of Bonaparte's gulls in other areas.

The lack of a feeding response by glaucous-winged gulls in the Capilano River agrees with observations of these birds in the Qualicum River in 1979 and 1980. However, in the Qualicum, unlike the Capilano, there was an apparent aggregation response by the gulls. This difference is probably a reflection of the large number of alternative food sources available in the city. In particular, the proximity of Stanley Park to the mouth of the Capilano River affords numerous opportunities for scavenging by the gulls.

Predation by other bird species on juvenile coho and chinook salmon also did not appear to be an important factor limiting smolt survival in the Capilano system.

8: GENERAL DISCUSSION

In the present study, it has been shown that the impact of bird predators on juvenile chinook in the Big Qualicum River can be substantial. Even when the fish released were healthy, large numbers of chinook did not reach the mouth of the river. Approximately 300,000 chinook (10-12% of migration) were captured by birds within 2 km of the hatchery.

Bonaparte's gulls exhibited the most pronounced aggregation and feeding responses to the chinook, and accounted for the majority of bird predation in normal years. Although the original intention was to examine the impact of Bonaparte's gulls alone on hatchery-reared salmonids, large numerical responses by many other bird species in 1981 necessitated the inclusion of these species in the analyses. For most species, it was infeasible to collect all the necessary information to enable accurate assessment of the amount of predation. The quantitative data on bird predators other than gulls have limited usefulness except in providing an indication of potential impacts. In particular, estimates from 1981 set upper limits to both the numerical and feeding responses of the birds. The more important aspect of this study is that it provides a basis for suggesting practical ways to alleviate bird predation.

The data suggest that avian predation will be lower if salmonid releases are delayed until late in the season, if they are given access late in the day, and if they are released on high tides. Numbers of loons, mergansers and scoters decrease throughout April, May and June as the birds leave for the breeding grounds or, in the case of mergansers, lose their flight feathers and move to more protected areas. These three species had declined to very low numbers by early June in all years of this study.

Delaying releases will probably not, however, lessen predation by Bonaparte's gulls. Although most of the mature birds have left the Qualicum area by the end of May, large numbers of juvenile gulls remain at least to mid-July. By this time, mature gulls in transition plumage have begun to return to the coast (Chris Wood pers. comm.).

Arctic loons, mergansers and harlequin ducks were more abundant in the estuary early in the day, and were uncommon late in the afternoon. Therefore, by releasing the fish late in the day predation by these species could be reduced. Further, feeding rates of most of the birds (in terms of the proportions feeding) were usually at a maximum at dawn in normal years. If releases begin in the late afternoon (or preferably at night), the birds may already be satiated.

Gull predation will be minimized if releases occur on high tides. For years in which the fish released are healthy, this study indicates that Bonaparte's gulls are ineffective at feeding on juvenile salmonids at tidal heights greater than 3 m in the Big Qualicum River. Bonaparte's gulls will have minimum opportunity to feed on fish if the days of release are selected so that tides are less than 3 m for the smallest possible number of daylight hours. The best days in this respect are those when one of the low tides is only slightly greater than 3 m. In this case, the other low tide is not extreme and the total time during which the birds can feed efficiently will be minimized. The worst days are those when there are two low tides less than 3 m within daylight hours. During the chinook release in 1980, tides were less than 3 m for a minimum of 6 h in the former case and up to 9.5 h in the latter case. Days with the lowest low tides are intermediate between the two extremes.

Although it is possible that bird predation could be reduced by releasing the fish during stormy weather, results do not indicate that harsh weather adversely affects numbers of birds in the area or feeding and success rates. Strong winds and rough surf do not affect gull predation, except at high tides, as these birds usually feed inside the surf zone.

Bonaparte's gulls were found to be extremely efficient predators on juvenile chinook salmon, both when the chinook had impaired vision and when they were healthy. In fact, as demonstrated in Fig. 5, the number of Bonaparte's gulls recorded in the estuary was a good indicator of the relative numbers of chinook descending the river. In the initial stages of this study, the possibility of a threshold number of chinook below which there would be no noticeable aggregation response by the gulls was considered. However, the speed and magnitude of the response by Bonaparte's gulls and their high capture success rates at low chinook densities (Figs. 10-11) imply that release schedules giving access to small numbers of fish at a time will not increase the likelihood of fish escaping predation.

The lower predation rates observed for the forced releases, as opposed to the passive releases, in 1981 (Table 10) suggest that predation by birds could be reduced considerably if all releases from the hatchery were forced. As it takes a few hours for birds to respond to the releases and as they have finite feeding capacities, there will be some upper limit on the numbers of fish ingested, regardless of the size of the release. Percent predation will be smaller if greater numbers of fish are shunted through the estuary, provided the residence period of fish in the estuary is brief.

In section 3, it was demonstrated that residency periods of both coho and chinook were short (often as small as 1-2 h). However, short residence periods do not necessarily imply that juvenile salmon would not benefit from staying in the estuary to forage or to adjust to ocean salinities. Survival rates of the fish could improve if they utilized the estuary to a larger extent. More study is needed to determine the capacity of the Big Qualicum estuary to provide food for juvenile salmonids and to determine the means to increase capacity.

The extent of predation by piscivorous birds in the Big Qualicum River was considerably lower for coho smolts than chinook fingerlings. This is interesting as smolt-to-adult survival rates of hatchery-reared Big Qualicum coho are similar to those of wild coho stocks, whereas smolt-to-adult survival rates of artificially reared chinook are somewhat lower than those for natural stocks (Ted Perry pers. comm.). There are two possible reasons why birds, particularly Bonaparte's gulls, have relatively little impact on coho. First, coho smolts are larger than chinook fingerlings and therefore more difficult for the birds to capture and manipulate. Second, whereas chinook were observed to descend the river at all times of the day, coho smolts were rarely seen downstream from the highway bridge except in late afternoon and early evening. Coho smolts in the lower reaches of the river aggregated beneath the highway bridge. It is possible that they used this area to adjust to ocean salinities, but they may also have used the bridge as a refuge from predation. The highway bridge is the last effective refuge from birds until fish reach the mouth of the river.

As little bird predation was observed on juvenile coho and chinook at the mouth of the Capilano River, it appears that results from the Big Qualicum River are not necessarily applicable to other systems. Other workers have also found that bird predation may be unimportant in some rivers. For example, Mossman (1959) concluded that gull predation probably did not affect the salmon population on the Kvichak River in Alaska. It is likely that each system is unique in terms of the amount of predation it suffers.

Chris Wood has carried out regular censuses of birds in other river systems in the Qualicum-Bowser area on Vancouver Island. His censuses included the Little Qualicum River and the Rosewall Creek-Mud Bay area, both of which have hatcheries located upstream, and the Englishman River which does not have an enhancement facility. Between May 3 and July 31, 1981, he counted less than 50 Bonaparte's gulls on the Englishman River and less than 100 Bonaparte's gulls on the Little Qualicum River, except on one occasion. The exception was the morning of May 31 when he recorded more than 200 Bonaparte's gulls in the Little Qualicum estuary. This was the first census conducted after a release of 1,180,000 chinook fingerlings from the Little Qualicum hatchery on May 27. By the time of the next census on June 9, there were less than 50 Bonaparte's gulls present in the estuary.

Thus, although there was a numerical response by Bonaparte's gulls to the Little Qualicum chinook, it does not appear to have been as pronounced or prolonged as that to the Big Qualicum chinook. There are two possible reasons for this difference. First, the Little Qualicum estuary is considerably larger than the Big Qualicum estuary, so that chinook would have been dispersed over a larger area. Second, fewer chinook were released from the Little Qualicum hatchery.

These data indicate that other hatcheries in the area may not suffer predation by Bonaparte's gulls to the same extent as the Big Qualicum. However, the fact that predation can be intense in at least one situation demonstrates the necessity for evaluating predation pressure in other systems. In particular, there is a need for more comprehensive studies on predation, and on the means to reduce predation, in systems located downstream from salmonid enhancement facilities. It is futile to invest capital in enhancing the salmonid stocks when birds, rather than fishermen, harvest the excess.

Despite heavy bird predation in the Big Qualicum River, major predator control schemes such as those that have taken place in the past are not recommended. Such schemes are often expensive and have limited short-term effects on predator populations. The destruction of one predator species may also result in numerical increases in other predators or competitors of salmonids (Hubbs 1940, Vladykov 1943).

In the Big Qualicum River, most bird predators that feed on salmonids are migratory species rather than residents of the area. Therefore, it would be particularly impractical to initiate predator controls in this system.

9: RECOMMENDATIONS

In the following recommendations, possible means of alleviating avian predation on juvenile coho and chinook in the Big Qualicum estuary are outlined, but constraints pertaining to the feasibility of putting these recommendations into practice are not taken into account, and their compatibility with other factors affecting early survival is not considered.

1. All salmonid releases should be delayed at least until early June and preferably until mid-June. By this time, most Arctic loons and scoters will have disappeared from the area. The period from mid- to late June is also a time when most of the non-breeding male mergansers (which are common in the Big Qualicum in May) have begun to lose flight feathers and move to more protected areas, and a time when mergansers chicks are not yet large enough to take fingerlings or smolts (Chris Wood pers. comm.). In addition, the number of people camping around the mouth of the river increases in June and deters gull-predation in several ways. Campers disturb gulls by bringing their boats upriver and by recreational activities such as throwing rocks at the birds. Campers also provide alternative food sources in the form of fish heads and entrails. Fish remains attract bald eagles which invariably disrupt feeding by gulls, and sometimes results in them leaving the area altogether.

2. The river bed could be dredged to deepen the channel sufficiently so that Bonaparte's gulls are less efficient at catching salmonids i.e., so that the water depth is greater than 80 cm at low tide. The river mouth should also be dredged so that access from the river is not inhibited at extremely low tides.

3. The estuary is sufficiently small that it might be possible to put netting across the river between the highway bridge and the river mouth so as to prevent gulls from having access to fish at low tide.

4. More refuges for fish could be established along the river. At present, once fish leave the shelter provided beneath the highway bridge, they have no protection from gulls at low tides until they reach the river-mouth.

5. Fish releases should be geared to the tides and time of day. All releases should take place at night and preferably on nights when the tide is low the following afternoon rather than in the morning. Early morning low tides should be avoided, as maximum numbers of birds were ususally recorded at this time. Hunger levels will also be at a maximum early in the day.

Dates for the releases should be selected to maximize the amount of time for which tides are greater than 3 m over the following 2-3 days.

6. Much bird predation could be avoided if fish are forced out of the hatchery. It would be preferable to release all fish at once, but if this is not possible releases should be well-spaced so that bird numbers do not build up.

7. It is possible that if releases were coordinated with those from nearby hatcheries, the predator load would be spread over a larger area.

8. Bird predation within the estuary could be avoided entirely if there were some means of ensuring that the fish by-passed the area. For example, fish could be transported directly from the hatchery to the sea. (This possibility was first suggested by Gharrett (1955) based on preliminary experiments on coho and chinook. Although he felt that the results warranted further investigation, there have been few subsequent attempts to introduce hatchery fish directly into estuarine waters.) Alternatively, a pipeline, or some other type of construction to channel the fish, could be constructed between the hatchery and the river mouth. Finally, the river bed beneath the highway bridge could be dredged to create a deep pool in which fish could be held behind screens until high tide. This would also provide them with time to adjust to the increased salinities of the estuary.

9. A major recommendation is that more research be done on this system, particularly on residency requirements of healthy fish, the usefulness of the estuary for growth, the necessity for a period of time to adjust to ocean salinities, and predation by other species in near-shore regions beyond the mouth of the river.

10. Predator control schemes for birds in the Big Qualicum area are not recommended because the bird species that have the greatest impact on juvenile salmonids are migratory at the time of the releases. Control schemes would be fruitless as these species exist along the coast in large numbers.

10: EFFECTS OF IMPLEMENTING SOME RECOMMENDATIONS IN 1982

On the basis of the results found in this study, some of the recommendations outlined above were implemented for the releases of Big Qualicum chinook in 1982. Principal modifications to the release schedule in 1982 were:

1. A delay in release-timing to alleviate predation by migratory birds, particularly Arctic loons, which pass through the area in large numbers from early May to early

June. Most of the chinook reared in the hatchery (3,769,000 fish) were given access to the river on 11 June, slightly later previous years. A second release of 52,500 (marked) chinook was made on 22 June. No releases occurred prior to 11 June.

2. Scheduling of releases for times when the tides were least favourable for predation. The main release was initiated at dusk on a night when the tide was high the following morning and low in the afternoon. A date when low tides were also moderate over the next 3-4 days was selected. It happened to occur on a weekend, at a time when many campers and fishermen were present to disrupt activity by the birds.

3. Reduction in the length of the out-migration period. Chinook that had not migrated by the morning of 14 June were seined out of the rearing channels.

To determine the effects of these innovations on predation rates, I monitored the amount of bird predation during the 1982 releases, using techniques similar to those employed during the previous three years.

Methods

In 1982 I conducted only one census to determine how quickly chinook left the river. Fish remaining in the area between the hatchery and the river mouth were counted at 1400 h on 15 June, about 89 h after the beginning of the main release. Birds present in the area between the highway bridge and about 1 km offshore from the mouth of the river were censused every three hours from dawn to dusk on 11-16 June, inclusive. Additional counts were made by hatchery personnel once or twice a day from 18-23 June. The number of chinook taken by Bonaparte's gulls was estimated by the methods used in 1981. Success rates over different tidal heights (water depths) and chinook densities were recorded. Estimates of the total number of successful strikes made by all birds feeding in the area were also calculated. Records of feeding activity were used as a basis for making one estimate of the overall impact of Bonaparte's gulls. Other estimates, except those for mergansers, were calculated from the average and maximum numbers of birds present in the estuary each day and the assumed consumption rates and diet compositions used in 1979 and 1980 (Table 6). Merganser predation was roughly calculated as one-fifth of the 1980 totals (since mergansers had only four days in 1982, instead of the 20 in 1980, to prey on chinook).

Results (compared to previous years)

Of the 3,769,000 chinook released on 11 June, there were only about 11,500 remaining in the river 89 h later. Most fish apparently passed quickly through the estuary, as they did in 1981. This suggests that questions of residence requirements warrant little consideration when designing release schedules for Big Qualicum chinook.

As in previous years, there was a definite mumerical response by Bonaparte's gulls to the chinook (Fig. 13). Prior to the release at dusk on 11 June, fewer than 100 Bonaparte's gulls were present in the estuary. By dawn the next day the number was even further reduced but continued to climb rapidly during the day, and over the next two days. This increase in numbers was not, however, as rapid as those of 1981 (Fig. 5). The difference may be attributable to modifications in the release schedule. Because the fish were first given access to the river at dusk in 1982, many had probably already passed through the system by first light the next day. Thus the density of fish in the estuary at dawn on 12 June may have been quite low. In addition, most of these fish were inaccessible to Bonaparte's gulls because the tide was high. I found that, as in 1980, the birds were ineffective predators on chinook at tidal heights exceeding 3.0 m. By the time the tide was sufficiently low for Bonaparte's gulls to feed, they were already partially satiated with other prey types and were probably searching less actively. (Data from previous years suggest that searching activity is greatest at dawn). In contrast, in 1981 some of the releases occurred near low tides during the morning and probably resulted in large concentrations of chinook in the estuary at a time when the fish were accessible to the gulls and the gulls were actively foraging.

At tides lower than 3.0 m, a maximum of 67.5% of the strikes made by Bonaparte's gulls resulted in successful captures of chinook. This is somewhat less than the maximum 93% success rate recorded in 1981. The maximum number of chinook taken by all birds feeding during any five-minute observation period was 233 in 1982, compared to 545 in 1981. Little "waste-feeding" (several successive records of captures of fish that were subsequently dropped) by Bonaparte's gulls was recorded in 1982, although it was frequently observed in 1981.

Peak numbers of Bonaparte's gulls were recorded in the estuary at 1700 h on 14 June. By this stage more than 95% of the chinook had already left. This probably accounts for the rapid subsequent decrease in numbers (Fig. 13). The peak of 698 Bonaparte's gulls contrasts dramatically with peaks of almost 1,700 in 1981 and about 1,400 in 1980. I am uncertain whether this reduction in maximum numbers can be attributed to delaying the release, whether the chinook were present for an insufficient time to allow further build-up, or whether the lack of releases prior to 11 June caused the birds to stop using the

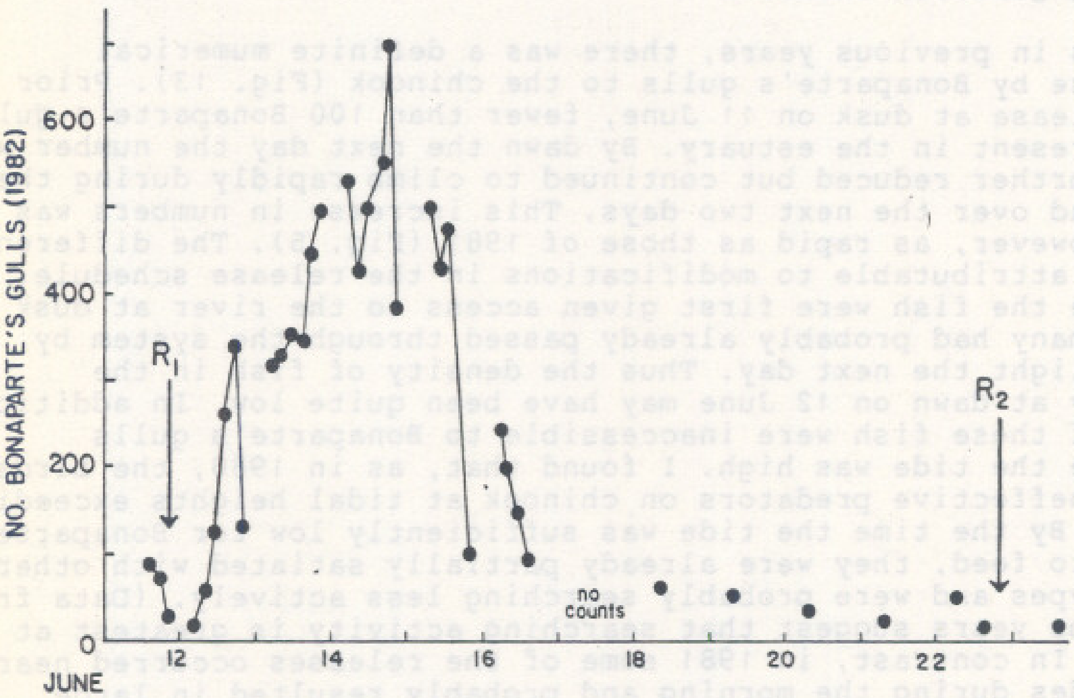


Figure 13. Numbers of Bonaparte's gulls in the Big Qualicum estuary during the chinook fingerling releases in 1982. R_1 indicates first release of 3,769,000 fish, R_2 indicates second release of 52,500 fish.

Big Qualicum estuary as a potential feeding ground. Data from previous years do not provide evidence for a seasonal decrease in numbers of Bonaparte's gulls.

There was, however, a definite seasonal decrease in numbers of Arctic loons. In 1982, a maximum of two Arctic loons were seen during any one census. This contrasts with maximum numbers of 73 and 680 in 1980 and 1981, respectively. It suggests that the breeding migration of Arctic loons in 1982 was almost completely over by 11 June.

The maximum number of glaucous-winged gulls in 1982 was 131, compared with 360 and 850 in 1980 and 1981, respectively. Corresponding maximums for harlequin ducks were 178, 90 and 290. A maximum of 8 adult mergansers and up to 16 chicks were observed in the estuary in 1982. Larger numbers were probably present upstream. As in 1980, glaucous-winged gulls and harlequin ducks were rarely observed capturing chinook. In 1981, both species of birds consumed chinook continuously during releases.

The overall estimated impact of the six most abundant piscivorous birds was small, totalling only 1.23-1.46% of the main chinook release (Table 14). These figures may even be over-estimates. For Bonaparte's gulls, the feeding observation estimates, which are the most accurate, were far less than either the "average" or "maximum" estimates included in the column totals. Also, the assumption that merganser predation in 1982 was about one-fifth of the 1980 levels probably over-estimates merganser predation as there were likely fewer during the 1982 release than in 1980. (Male mergansers lose their flight feathers and move to more protected areas in late May and early June).

When these estimates are compared with those from 1980 and 1981 (Table 15), the substantial reduction in bird predation achieved in 1982 is evident. Based on the feeding observations, consumption of chinook by Bonaparte's gulls in 1982 was only 7.9% of that in 1980. Total predation rates by all species of birds in 1982 were only about 15% of those in 1980 and 5% of those in 1981.

Conclusions

Modifications to the release-schedule in 1982 had three main effects. First, delaying the main chinook release until mid-June almost totally avoided predation by Arctic loons, and may have reduced merganser predation. Second, gearing the releases to the tides and times of day reduced the proportion of the day that Bonaparte's gulls could feed on chinook. Third, forcing chinook out of the hatchery after a period of volitional migration substantially reduced the number of days over which predation could occur. A combination of all three of these strategies may have prevented a large build-up of Bonaparte's

Table 14. Estimated number of juvenile chinook taken by piscivorous birds in the Big Qualicum River in 1982. See section 6 for definitions of average and maximum.

Species	Feeding Observations	Average	Maximum
Bonaparte's	21,200	32,500	39,800
Glaucous-winged		600	900
Loons		50	250
Mergansers		11,200	11,200
Harlequins		1 900	2,800
Scoters		< 50	< 50
Total		46,300	55,000
Total as % of release		1.23	1.46

Table 15. Some comparisons of estimated predation rates on Big Qualicum juvenile chinook over the years 1980-82. See section 6 for definitions of average and maximum.

	1980	1981	1982
Bonaparte's (Feeding observations)	267,900	214,200	21,200
Total bird predation (averages)	300,900	856,500	46,300
Total bird predation (maximums)	354,200	1,260,400	55,000

gulls.

Although the estimated predation rates for 1982 can probably be considered insignificant, further reductions could possibly be achieved by totally preventing chinook from entering the river during daylight hours.

11: SUMMARY

1. In 1981, few juvenile coho and chinook salmon resided in the Big Qualicum estuary following release from the hatchery. Up to 50% of the chinook left the estuary within six hours of entering the river. Chinook also left the river rapidly in 1982. Residence periods for coho were slightly longer. In 1982, small numbers of coho (<5,000) resided in the river for up to 18 days.

2. Five major factors were found to affect the numbers of piscivorous birds in the Big Qualicum estuary: coho abundance, chinook abundance, time of season, time of day, and tidal height.

3. Bonaparte's gulls and Arctic loons were the only bird species to respond numerically to coho releases.

4. Bonaparte's gulls exhibited the most pronounced aggregation responses to juvenile salmonids, particularly chinook. Up to 1,700 Bonaparte's gulls responded to the chinook releases in 1981. There was little numerical response by other birds to the chinook releases in 1979 and 1980, but in 1981, glaucous-winged gulls, Arctic loons, and harlequin ducks all keyed into the chinook releases. Mergansers and scoters were also observed capturing chinook fingerlings in that year.

5. The exaggerated responses of birds to chinook abundance in 1981 were due to two factors: a nutrient deficiency which severely impaired the fishes' vision, and an earlier timing of releases. Chinook were released in mid-May when numbers of migratory species, such as Arctic loons and mergansers, were high. A maximum of 2,348 piscivorous birds were recorded on one occasion in the Big Qualicum estuary in 1981.

6. Numbers of loons, mergansers and scoters decreased throughout the season. In contrast, there was a seasonal increase in the numbers of glaucous-winged gulls and harlequin ducks.

7. Loons, mergansers and harlequin ducks reached maximum numbers in the estuary early in the day.

8. Bonaparte's gulls were able to feed effectively on healthy juvenile chinook and coho only at tides below 3 m (or in water depths less than 80 cm). Tidal height was not found to affect feeding rates on partially-blind chinook which were taken continuously from dawn to dusk in 1981.

9. Glaucous-winged gulls, harlequin ducks and scoters fed extensively on chinook fingerlings in 1981, but not in the two previous years. Arctic loons and mergansers fed on chinook in all years.

10. Bonaparte's gulls were found to be extremely efficient predators on hatchery-reared juvenile chinook salmon. Up to 93% of their strike attempts resulted in successful captures of chinook. Up to 33% of the attempts on coho smolts were successful.

11. Flocks of Bonaparte's gulls destroyed up to 545 chinook each five-minute period in 1981 compared with 152 in 1980.

12. Flocks of glaucous-winged gulls consumed up to 1,848 chinook each five-minute period in 1981. They killed negligible numbers of chinook in the two previous years.

13. Flocks of Bonaparte's gulls ingested a maximum of 63 coho smolts each five-minute period. Glaucous-winged gulls were rarely seen taking coho smolts.

14. Bonaparte's gulls were found to be surprisingly good predators at very low chinook densities (less than 200 chinook in the feeding area). They captured up to 95% of the chinook migrating downstream near the beginning or end of releases from the hatchery in 1981. They captured 53-70% of groups of 25-200 healthy chinook fingerlings released upstream from the feeding area.

15. When there were large numbers of partially-blind chinook descending the river, Bonaparte's gulls engaged in a considerable amount of waste-feeding. They ate an average of only 12.4% of the chinook they captured, compared to 90.0% when chinook were healthy.

16. It was estimated that approximately 300,000 juvenile chinook (10-12% of total migration) are taken by the major bird predators in the Big Qualicum River in normal years. Bonaparte's gulls account for the majority of bird predation.

17. It was estimated that approximately 1,000,000 juvenile chinook salmon (almost 25% of the release) were taken by the major bird predators in the Big Qualicum River in 1981. Bonaparte's gulls did not take significantly more chinook than in normal years, and were not the major bird predators in that year. Most chinook were taken by glaucous-winged gulls. Arctic loons also consumed large numbers.

18. The amount of predation by piscivorous birds on coho smolts was considerably lower than that on chinook fingerlings in all years. Predation rates on coho smolts were about 2-4% of the total releases. The major avian predators on coho smolts were Bonaparte's gulls, Arctic loons and mergansers.

19. There was no apparent aggregation response by birds to a release of 360,000 chinook fingerlings and 36,000 coho smolts in the Capilano River in June, 1981. Feeding observations indicated that birds at the mouth of the Capilano River utilized juvenile

salmonids as food to a minimal extent. Bonaparte's gulls were absent from the system.

20. It was recommended that salmonid releases from the Big Qualicum hatchery should be delayed until early or mid-June, and that the releases should be geared to the tides and time of day. It was also suggested that the river bed could be dredged to decrease the efficiency of the Bonaparte's gulls as predators, or that some means of ensuring that the fish by-passed the area between the hatchery and the river-mouth could be devised.

21. In 1982, some of these recommendations were implemented for chinook. Releases were delayed to mid-June, focused mainly on high tides, and reduced considerably in duration. This resulted in chinook predation rates that were only about 15% of those in 1980 and 5% of those in 1981.

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APPENDIX

The bird species most commonly recorded in the Big Qualicum estuary during spring 1979-1981 (excluding woodpeckers and most perching birds of the order Passeriformes).

Order Gaviiformes (Loons)
- Common loon, *Gavia immer*
- Arctic loon, *G. arctica*

Order Podicipediformes (Grebes)
- Western grebe, *Aechmophorus occidentalis*
- Red-necked grebe, *Podiceps grisegena*
- Horned grebe, *P. auritus*

Order Pelecaniformes (Pelicans and Allies)
- Double-crested cormorant, *Phalacrocorax auritus*
- Pelagic cormorant, *P. pelagicus*

Order Anseriformes (Waterfowl)
- Canada goose, *Branta canadensis*
- Black brant, *B. nigricans*
- Mallard, *Anas platyrhynchos*
- American widgeon, *Mareca americana*
- Shoveller, *Spatula clypeata*
- Blue-winged teal, *Anas discors*
- Canvasback, *Aythya valisineria*
- Common goldeneye, *Bucephala clangula*
- Barrow's goldeneye, *B. islandica*
- Bufflehead, *B. albeola*
- Harlequin duck, *Histrionicus histrionicus*
- Common scoter, *Oidemia nigra*
- White-winged scoter, *Melanitta deglandi*
- Surf scoter, *M. perspicillata*
- Common merganser, *Mergus merganser*
- Red-breasted merganser, *M. serrator*

Order Falconiformes (Vultures, Hawks and Falcons)
- Bald eagle, *Haliaeetus leucocephalus*
- Osprey, *Pandion haliaetus*

Order Ciconiiformes (Herons and allies)
- Great blue heron, *Ardea herodias*

Order Charadriiformes (Shorebirds, Gulls and Alcids)
- Killdeer, *Charadrius vociferus*
- Solitary sandpiper, *Tringa solitaria*
- Spotted sandpiper, *Actitis macularia*
- Black turnstone, *Arenaria melanocephala*
- Rock sandpiper, *Erolia ptilocnemis*
- Western sandpiper, *Ereunetes mauri*
- Glaucous-winged gull, *Larus glaucescens*
- Herring gull, *L. argentatus*
- Thayer's gull, *L. argentatus thayeri*

California gull, *L. californicus*
Mew gull, *L. canus*
Bonaparte's gull, *L. philadelphia*
Arctic tern, *Sterna paradisaea*
Pigeon guillemot, *Cepphus columba*
Marbelled murrelet, *Brachyramphus marmoratum*

Order Coraciiformes (Kingfishers)
Belted kingfisher, *Megaceryle alcyon*

Order Passeriformes (Perching birds)
Northwestern crow, *Corvus caurinus*