Exxon Valdez Oil Spill
Restoration Project Final Report

Sound Ecosystem Assessment (SEA): Estimating Local Avian Predation Rates on Hatchery-Released Fry

Restoration Report 95320-Y
Final Report

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Sound Ecosystem Assessment (SEA):
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Final Report

Study History: Restoration Project 95320-Y began in 1995, and received funds for analysis and close-out in 1996. Project 95320-Y was part of the Sound Ecosystem Assessment program. This is the final report on activities conducted by this project.

Abstract: We estimated the mortality of hatchery-raised pink (Oncorhynchus gorbuscha) and chum (Oncorhynchus keta) salmon fry as a result of seabird predation near a Prince William Sound salmon hatchery. Field counts of seabirds and observations of feeding rates for several plunge-diving seabirds were obtained from a skiff during April, May, and June 1995. Several 100 birds of seven piscivorous species aggregated in front of the hatchery. Aggregations were largest in May and declined by early June. Consumption rates were determined from focal animal sampling and by calculation of energetic demand. Most of the per capita consumption rates based on behavioral data were lower than those calculated from energetic considerations. The use of energetic models and estimated fry movement rates provided a range of 2.7 to 5.9 million juvenile salmon (1.1% to 2.4% of released fry) consumed during the study period. Sixty-four percent of this range was attributed to differences between the energetics models; the remainder to the assumptions about fry movement rates. Early marine mortality of salmon fry resulting from seabird predation may increase in years of higher seabird abundance; however, mortality may be reduced by releasing fry later in the season when bird numbers have declined.

Gulls recorded during aerial surveys were significantly associated with spawning herring and with hatchery sites, but not with linear miles of herring spawn. The correlation of bird aggregations with the presence of small fish (spawning herring and hatchery locations) indicates that concentrations of forage fish have an important influence on the distribution of birds at sea during this time of the year. Bird numbers in all samples (boat counts, volunteer data, and aerial surveys) increased in May when fry were released. By June, boat counts and aerial surveys showed a decline in bird numbers suggesting that fry released from the hatcheries in April and May face considerably more risk of predation from birds than do fry released in June.

Key Words: salmon hatcheries, predation, pink salmon, chum salmon, seabirds, Arctic Tern, Black-legged Kittiwake, Mew Gull, Bonaparte's Gull, Marbled Murrelet, Common Merganser, Red-breasted Merganser, *Exxon Valdez*, Prince William Sound

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EXECUTIVE SUMMARY

The 'predator-prey relationship' hypothesis of SEA asserted that loss to predation is the most important variable element of pink salmon (Oncorhynchus gorbuscha) fry survival, and that the intensity of this predation depends on the availability of alternative prey such as macrozooplankton. This hypothesis is particularly relevant to predicting and managing the recovery of pink salmon populations from EVOS, and to the role of hatcheries in restoring these populations.

The objectives described in the 1995 Detailed Project Description were to record the size and composition of seabird foraging aggregations near one hatchery during the fry release period; to measure consumption rates for plunge-diving birds using focal-animal sampling; to collect data from volunteer observers at each hatchery site on the abundance of birds; and to estimate the magnitude of local predation on hatchery-released fry immediately following release, using the count data from this study and estimates of consumption rates from energetics models published in the literature.

We counted up to several hundred birds a day from a skiff during April, May, and June 1995 in front of Wally Noerenberg Hatchery. Aggregations were largest early in the study period and declined by early June. The ten most common species of birds present in these counts included seven piscivores; but 50% of all birds consisted of just the two most abundant species: Black-legged Kittiwakes (Rissa tridactyla) and Marbled Murrelets (Brachyramphus marmoratus).

Consumption rates were determined from focal animal sampling and by calculating the energetic demand of all piscivorous birds counted. We used three models of seabird energetics (Nagy 1987, Birt-Friesen et al. 1989). The models we chose to predict energetic demands were derived from measurements of field metabolic rates of seabirds. Differences between the data used to develop the allometric equations resulted in variation in the predicted field metabolic rates: Nagy's (1987) model included some tropical birds, while Birt-Friesen et al. (1989) presented models restricted to cold-water seabirds. Values predicted by Nagy (1987) were below those predicted by Birt-Friesen et al. (1989), presumably because warm-water species typically have lower metabolic rates than arctic and subarctic birds (Ellis 1984).

Most of the per capita consumption rates based on behavioral data were lower than those calculated from energetic considerations. The use of energetic models and estimated fry movement rates provided a range of 2.7-5.9 million juvenile pink and chum (Oncorhynchus keta) salmon (1.1% to 2.4% of released fry) consumed during the study period. Sixty-four percent of this range was attributed to differences between the energetics models; the remainder to the assumptions about fry movement rates. Early marine mortality of salmon fry resulting from seabird predation may increase in years of higher seabird abundance. This mortality might be reduced by releasing fry later in the season when bird numbers have declined.

An analysis of the distribution of white seabirds (largely gulls) based on five aerial surveys over western Prince William Sound indicated that gulls were associated with spawning herring and with hatchery sites. We suggest that the timing of salmon release (or outmigration) relative to that of spawning migrations by herring and other forage fish determines the magnitude of bird aggregations that feed on salmon fry. Further data is needed to confirm this.

INTRODUCTION

The 'predator-prey relationship' hypothesis of SEA asserted that loss to predation is the most important variable element of pink salmon fry survival, and that the intensity of this predation depends on the availability of alternative prey such as macrozooplankton. This hypothesis is particularly relevant to predicting and managing the recovery of pink salmon populations from EVOS, and to the role of hatcheries in restoring these populations. Field observations in 1994 suggest that in some cases, predation on young fish by birds may be as important as predation by larger fishes. One SEA project, Pink Salmon & Herring Predation (320-E), is designed to evaluate the significance of fish predation on 0-age class fishes. The goal of this project (95320-Y) is to estimate the localized intensity of bird predation on hatchery-released pink salmon fry.

Chapter one reports data on the size and composition of seabird aggregations in front of Wally Noerenberg Hatchery during the spring of 1995, and calculates the magnitude of predation by these birds on salmon fry. This chapter is presented as a draft manuscript to be submitted for publication (Scheel, D., K. R. Hough. Salmon fry predation by seabirds near an Alaskan hatchery). Chapter two presents additional data from this study that was not appropriate in the draft manuscript, including survey data on bird aggregations at the other four salmon hatcheries that operate in Prince William Sound, and an analysis of the spatial distribution of gulls based on aerial survey data.

OBJECTIVES

The objectives for this study are listed below. Our primary methods and results for objectives (1), (2), and (4) are reported in Ch. 1, and are not repeated elsewhere in the report. Supporting material and the complete results for objective (3) are included in Ch 2. As described in the 1995 Detailed Project Description, the objectives were to:

1) Record size and composition of seabird foraging aggregations near one hatchery-release site immediately pre-release, during release, and immediately post-release of salmon fry.

2) Sample behavior at foraging aggregations to measure dive and capture rates for avian foragers that bring prey to the surface before consuming them (e.g. gulls and terns).

3) Organize volunteer observers at each hatchery release site in the Sound to record the qualitative abundance and composition of foraging aggregations near hatcheries during pre-release, release, and post-release periods.

4) Using data from this proposal and literature values for consumption rates, estimate the extent of local predation on hatchery-released fry immediately following release.

CHAPTER 1: Salmon fry predation by seabirds near an Alaskan hatchery

SALMON FRY PREDATION BY SEABIRDS NEAR AN ALASKAN HATCHERY

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ABSTRACT

We estimated the mortality of hatchery-raised pink (Oncorhynchus gorbuscha) and chum (Oncorhynchus keta) salmon fry from seabird predation near a salmon hatchery in Lake Bay, Prince William Sound. Field counts of seabirds and observations of feeding rates for several plunge-diving seabirds were obtained during salmon fry releases between April and June 1995. Several hundred birds of seven piscivorous species aggregated in front of the hatchery. Aggregations were largest in May and declined by early June. Consumption rates were determined from focal animal sampling and by calculation of energetic demand. Most of the per capita consumption rates based on behavioral data were lower than those calculated from energetic considerations. From energetic models and fry movement rates, we estimated that 2.7 to 5.9 million juvenile salmon (1.1% to 2.4% of released fry) were consumed during the study period. Differences between the energetics models account for sixty-four percent of this range; assumptions about fry movement rates account for the remainder. Early marine mortality of salmon fry resulting from seabird predation may increase in years of higher seabird abundance; however, mortality may be reduced by releasing fry later in the season when bird numbers have declined.

INTRODUCTION

Schools of small fish are a concentrated food source, and often attract predators. Seabirds aggregate over and feed on schooling fish in the marine environment (Brown 1980, Hoffman et al. 1981, Duffy 1983, 1989), and in coastal waters such as rivers, streams (Wood 1985, Ruggerone 1986, Wood 1987a, 1987b, Kålås et al. 1993) and shallow-water estuaries (less than five meters deep. Bayer 1986, Kålås et al. 1993). Seabirds can consume 20% or more of local fish production (Furness & Monaghan 1987) and thus may be a substantial source of mortality. Studies of salmon production lost to seabirds have focused on chinook (Oncorhynchus tshawytscha), sockeye (Oncorhynchus nerka), and coho (Oncorhynchus kisutch) salmon (e.g. Ruggerone 1986; Wood 1987a, 1987b) in North America; and on Atlantic salmon (Salmo salar), Brown trout (Salmo trutta), and Arctic char (Salvelinus alpinus) in Europe (Kålås et al. 1993). Estimates of losses to seabird predators in these studies range between 1% and 65% of hatchery and/or wild salmon production.

The Sound Ecosystem Assessment program, currently taking place in Prince William Sound, Alaska, is attempting to identify major predators on juvenile pink salmon (Oncorhynchus gorbuscha) and to account for the early marine mortality of these fish. Predators of salmon fry are of particular interest because of the commercial value of salmon and because salmon production is supplemented by a large hatchery program. Wally Noerenberg Hatchery in northwestern Prince William Sound releases pink and chum (Oncorhynchus keta) salmon into a deep-water (to 70 m) estuary. In 1994, thousands of seabirds were observed in front of this hatchery (pers. comm. M. Willette, T. Cooney). This observation prompted our study.

We counted seabirds aggregated at the Wally Noerenberg hatchery and calculated seabird consumption of salmon fry based on models of seabird energetic demand. These were compared to calculations based on the capture rates of focal animals. We show that in 1995, a few hundred birds were present per day at this hatchery. These birds probably consumed less than 2.5 percent of hatchery production during the period of fry release. Seabirds were reportedly more abundant in front of this hatchery in 1994 than during our study. Mortality from seabird predation may be higher in years when birds are more abundant.

METHODS

Study site

Seabirds were counted in April-June 1995, in front of the Wally Noerenberg Hatchery, located at 60°48'N, 148°05'W on Lake Bay, Esther Island in Prince William Sound. The Sound is located in southcentral Alaska on the northern edge of the Gulf of Alaska (Fig. 1). Prince William Sound is a large, deep (to 476 fathoms), tidal estuarine system comprised of mountainous islands, protected embayments, and glacial fjords.

Wally Noerenberg Hatchery is owned and operated by the Prince William Sound Aquaculture Corporation. Between 29 April and 15 June 1995, the hatchery released into Lake Bay 169.4 million pink salmon fry at an average release weight of 0.29 grams and 72.3 million chum salmon fry at 0.88 grams (Prince William Sound Aquaculture Corporation). Dense schools of fry were visible nearshore throughout the entire study period following the first release. Fry were observed initially in Lake Bay, and within a day or two were also seen throughout Quillian Bay, at Esther Point, and along the west shore of Esther Island.

Bird counts

During the periods of 25 April to 18 May and 3-7 June 1995, we counted birds once or twice daily in Lake Bay, Quillian Bay, and immediately in front of these bays in Wells Passage (Fig. 1). Two observers in a small open skiff counted all birds seen over the water. We ran the boat approximately 50 meters from shore along both sides of each bay and birds were counted on both sides of the boat from the adjacent shore out to the middle of the bay. In area 14, that was open to Wells Passage, birds were counted to 100 meters on either side of the boat. In this count area, to survey further offshore, we made two transects: the first was 50 meters from the shore, and the second was approximately 250 meters off shore. Distances were measured using a Leitz optical rangefinder. At times, weather prohibited counting the entire study area. Our analyses include only days when all fourteen count areas were surveyed ($\underline{N}$=21). Birds were identified to species where possible or to the finest taxonomic resolution discernable in the field. The majority of birds were identified to species.

Consumption of fry

Only the most abundant piscivorous seabirds (Table 1) were included in estimates of consumption of fry. Plunge-diving birds (Haney & Stone 1988) were classified as piscivores if fish were listed as a primary component of their diet (Ehrlich et. al 1988) and they were observed feeding on fry; pursuit-diving birds were considered to be piscivores if fish were listed as a primary component of their diet and they were observed in mixed-species foraging flocks near salmon fry.

Per capita consumption was calculated using two methods. For three plunge-diving species, consumption was calculated based on fry capture rates observed during focal animal sampling. For these species as well as four others, consumption rates were also calculated using energetics models, and the energy content of fry. We compared the results of these two methods.

Behavioral data

Focal animal sampling was conducted on three species: Black-legged Kittiwakes, Bonaparte's Gulls, and Arctic Terns. These plunge-diving piscivores were observed during feeding bouts in mixed-species flocks. An individual active bird in the flock was chosen and followed by binoculars for a period of three to five minutes. Sampling ended after five minutes or when the bird flew out of view. If the bird could not be observed for at least three minutes, the sample was discarded. Samples were not adjusted for the proportion of time an individual bird spent in non-foraging activities (e.g. resting). A successful capture was recorded if we saw a small fish in the beak when the bird emerged from a plunge dive.

Capture rates were calculated for each of the three species as the average number of successful captures per minute. Estimates of the time per day spent in active feeding were made from the reported behavior of radio-tagged Kittiwakes (Irons 1992). We are aware of no other literature on the daily active foraging times of terns or gulls, and so used our calculation for kittiwakes as the foraging time for all species. Daily per capita consumption was estimated for each species as the capture rate times the daily time spent actively feeding.

Energetic models

Energetic modeling provides an alternative way to calculate daily consumption of fry by seabirds. We used mass-metabolic rate regression equations available in the literature (Table 2) to calculate field metabolic rates (FMRs) for the common piscivores in our study area. These models provided a range of predicted FMRs (Fig. 2). We compared measured FMRs of Black-legged Kittiwakes (Gabrielsen et al. 1987) and Arctic Terns (Uttley et al. 1994) to the model predictions. Measured FMRs for the other species were not available.

Average release weights for each pen of pink and chum salmon fry were obtained from the Prince William Sound Aquaculture Corporation and growth rate of pink salmon fry was obtained from M. Willette (Alaska Department of Fish & Game, pers. comm.). Growth was measured from recaptured coded-wire tagged fry and calculated to be 4.2% body weight per day for fry released from Wally Noerenberg Hatchery during 1995. Pink and chum fry were found in mixed schools in front of the hatchery and were likely feeding on the same prey. We therefore assumed that the measured growth rate of pink salmon fry applied to chum salmon fry as well. We calculated the weight of each cohort of fry, starting with the measured release weight on the day of release, for each day until 15 June 1995. The mass of the average fry in front of the hatchery changed depending on fry growth, release of new fry and loss of fry to movement or predation. To estimate the mass of the average fry on a given day, we assumed that fry from each release cohort left the area at a fixed rate per day. The average mass of fry remaining was then calculated from known release weights, dates, and growth rates. We used two different estimates of fry departure rates: a low movement rate of 2.5% departure per day and a high rate of 50% departure per day (Fig. 3). Higher movement rates resulted in less growth before fry left the area, and hence lower mass per fry on average.

The energy content of pink salmon fry captured on May 31 at Esther Point in Wells Passage (Fig. 1) was measured using bomb calorimetry ($\underline{x}$=3.21 kilojoules per gram wet weight, $\underline{N}$=62. A.J. Paul, unpublished data). We recognize that the energetic content may differ between pink and chum fry and may change throughout the season. However, to simplify our calculations, we used this value as a reasonable approximation of salmon energy content for the purposes of this paper. We used this value as the energy content of pink and chum salmon throughout the study period. For each cohort of fry, the energy content per fry was calculated for each day as the weight of the fry times 3.21 kJ/g. Finally, we calculated the energy content of the average fry in front of the hatchery as the energy content for each cohort of fry releases weighted by the abundance of fry from that cohort assuming low or high movement rates (Fig. 3).

Seabird daily per capita consumption rates were calculated as the predicted FMRs for each species divided by the salmon fry energy content. Per capita consumption was multiplied by the number of seabirds present to estimate total consumption of fry each day. These were summed to calculate cumulative consumption over the study period. We assumed birds ate sufficient fry to meet their energy demands. No corrections were made for weight gain or loss by the birds, for less than 100% salmon in the diet, or for less than 100% digestion efficiency.

RESULTS

Numbers of birds

Sixty-five species of birds were observed during boat counts in this study. However, ten species collectively made up 93% of all counts (Table 1). Of these, seven were piscivores. Overall, piscivorous birds increased in the count area during the period of fry releases (Fig. 4). Black-legged Kittiwakes arrived and dispersed quickly, apparently in response to each individual release, although this relationship was not significant (Kruskal-Wallis ANOVA, $\underline{df}=2$, $\underline{T}=4.6$, $\underline{p}=0.098$). Marbled Murrelet numbers began to increase about one week following the start of releases and continued to increase throughout the release period. A notable exception to this trend was the decrease in Marbled Murrelet numbers beginning 11 May, which corresponded to a ten-day period (8-17 May) in which there was only one fry release (13 May). Murrelet numbers began to rise again following the 13 May release (Fig. 4). Groups of Bonaparte's Gulls and Arctic Terns fed in the area for several days and then moved on. Red-breasted Mergansers increased gradually through mid-May and declined by early June. Common mergansers were abundant initially, but declined beginning in early May. Mew gulls were present in small numbers throughout.

Observed feeding rates

Black-legged Kittiwakes, Arctic Terns, and Bonaparte's Gulls were observed in mixed-species foraging flocks consuming fry at rates from 60-100 fry per hour (Table 3). Multiplied by the estimated 2.3 hours of foraging per day, this yielded estimates of daily per capita consumption from 150 fry per day for Bonaparte's gulls to 230 fry per day for Black-legged Kittiwakes. Compared to daily per capita consumption rates based on a 'standard' average fry (from May 10, mass = 0.53 g), these estimates were lower than estimates from the energetic models of Birt-Friesen et al. (1989). They were lower than estimates from Nagy (1987) for Kittiwakes and Bonaparte's Gulls, but slightly higher for Arctic Terns (Fig. 5).

Cumulative mortality to fry

Cumulative mortality to fry reflected differences in the energetics models (Fig. 6). Using Nagy's (1987) model, we arrived at a total mortality from birds of 2.7 to 3.6 million fry (for low and high fry movement respectively). Birt-Friesen et al.'s (1989) models gave estimates of 3.8 to

5.9 million fry (all cold-water seabirds, low fry movement and cold-water flapping seabirds, high fry movement respectively).

During 1995, 241.7 million pink and chum fry were released into Lake Bay. Our estimates of mortality from fish-eating birds represent between 1.1 and 2.4 percent of the total release. Our assumptions about the movement rates of fry account for 36% of this range in estimates, while differences between the energetic models account for the remaining 64% (Fig. 6).

DISCUSSION

We estimated total fry consumed by birds using three models of seabird energetics (Nagy 1987, Birt-Friesen et al. 1989). These results were compared to a daily consumption rate estimated from focal-animal samples on actively foraging birds. Using these methods, we were able to provide a range of estimates, from low values predicted by the behavioral sampling and the energetic model of Nagy (1987) to a high value predicted by Birt-Friesen et al. (1989).

The models we chose to predict energetic demands were derived from measurements of field metabolic rates of seabirds. Other models of seabird energetics were available, but predicted basal metabolic rates (Ellis 1984, Diamond et al. 1993, Gabrielsen 1994). To avoid estimating a conversion between basal and field metabolic rates, we restricted our analyses to models that were based on FMRs. Nonetheless, more than half of the difference between our low and our high estimates was attributed to differences between the three energetic models.

Differences between the data used to develop the FMR allometric equations likely explain why the models vary. Nagy's (1987) model included 33% warm-water birds, 13% non-designated species and only 53% cold-water species (following Birt-Friesen et al. 1989, N=15 samples from 10 species). In contrast, Birt-Friesen et al. (1989) presented models restricted to cold-water seabirds. Values predicted by Nagy (1987) were below those predicted by Birt-Friesen et al. (1989), presumably because Nagy included warm-water species, which typically have lower metabolic rates than arctic and subarctic birds (Ellis 1984).

We presented two models from Birt-Friesen et al. (1989): one for all seabirds in cold-water regions (N=16 samples from 16 species), the second for flapping seabirds in cold-water (N=8 samples from 8 species). The latter model predicts higher FMRs, because flapping is energetically expensive. While the first model is based on a larger sample size and is presumably more general, it includes data from a variety of species not typical of our study area. The model for cold-water flapping seabirds includes Black-legged Kittiwakes, two murre species, two petrel species, Black Guillemots, Least Auklets, and Northern Gannets. These species are similar to the birds aggregated in front of Wally Noerenberg Hatchery during this study. Although the cold-water model for flapping seabirds encompasses a small range of body sizes (Montevecchi et al. 1992), it includes species that span a greater range in body size than the seven piscivores in our study. We therefore this model is most appropriate for our purposes.

There are several possible reasons why estimates from the behavioral data differ from those of the energetics models. First, we applied a literature value for Black-legged Kittiwakes foraging time to Arctic Terns and Bonaparte's Gulls because of a lack of published values for the latter two species. It is not known how this estimate compares to true values for these birds. Second, we did not correct for the fact that bird diets may include items other than salmon fry. We saw birds that appeared to capture and consume a prey item without having fish visible in their beaks. These birds may have been consuming smaller prey such as amphipods. Birds may also have been selectively preying on larger fry in a school (but see Kålås et al. 1993 for a report of birds selectively taking smaller, not larger, fry). If birds derived a portion of their diet from zooplankton or selectively chose larger salmon fry, fewer fry would be required to meet their energetic demands. Third, FMR allometric equations were based on values obtained during the breeding season, primarily during chick-rearing (Nagy 1987, Birt-Friesen et al. 1989). Breeding birds may have higher energy demands than non-breeders (Gabrielsen & Mehlum 1989, Baird 1990; Gabrielsen 1994). Although our study overlapped the early breeding season for some species (Isleib & Kessel 1973), most birds were not rearing chicks and thus may have had lower energetic demands than predicted by the FMR equations. The magnitude of these biases are unknown. Fourth, we assumed a digestive efficiency of 100% in our calculations. Measures of digestive efficiency for seabirds range from 69% (White-chinned Petrel chicks fed light fish, Jackson 1986) to 82% (for piscivorous birds, Ricklefs 1974 in Furness & Monaghan 1987). If digestive efficiency was 80%, our estimated consumption from energetic models would increase by twenty-five percent. Fifth, foraging birds may turn over at a site, so that counts of the birds in the area at any one time would underestimate the number of birds feeding there in the course of a day. We were unable to estimate the magnitude of this bias.

The behavioral estimates overlapped the energetic estimates at the lower end only. Two of the known biases in our models suggest that the energetics calculations would overestimate consumption, which may explain why energetic estimates were higher than those from focal animal sampling. However, the measured FMRs for both Black-legged Kittiwakes (Gabrielsen et al. 1987) and Arctic Terns (Uttley et al. 1994) fell towards the higher estimates of FMR (Fig. 2), indicating that our calculations of energetic demand were reasonable.

We estimated a cumulative mortality to fry of 1.1-2.4%. We were unable to partition this mortality between pink and chum salmon fry. This estimate falls toward the low end of estimates of salmon losses to bird predators: Wood (1987b) found loss rates to birds as high as 65%. However, several authors (Ruggerone 1986, Wood 1987a, Kålås et al. 1993) report rates in the range of 1-10%, rates very close to our estimates. A similar study on fish predators at hatcheries (Collis & Beaty 1995) found that Northern Squawfish aggregated to feed at salmon release sites, but total consumption was not calculated due to difficulties of estimating predator numbers. As part of the Sound Ecosystem Assessment program, estimates of fish predation rates on juvenile pink salmon are being made by other researchers (G. Thomas, M. Willette) using fisheries acoustics and examination of stomach contents. Their results along with ours will allow a comparison of the relative magnitude of fish and avian predation on pink salmon in Prince William Sound.

We were told by residents at the hatchery that there were relatively few birds present the year of our study, and that in previous years, 'thousands' of birds were attracted to fry releases and fed in the areas we were surveying. Losses of salmon fry to seabirds would clearly be greater in years when many more birds were present, which would be consistent with comparable or higher predation rates reported from other studies of seabirds aggregating to feed on salmon (Ruggerone 1986, Wood 1987a, 1987b, Kålås et al. 1993). The general decline in the numbers of all piscivorous birds at the hatchery by early June may be due to the constraints on seabird foraging as birds enter the nesting season. This suggests that releasing fry later in the year would reduce losses to avian predators.

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Table 1: Ten species of birds accounted for 93% of counts in the hatchery area. The body masses of the seven piscivorous species (P) are given.

Common name	Species	Diet	BM (kg)	Total count	Prop.
All species				7333	1.00
Black-legged Kittiwake	*Rissa tridactyla*	P	0.383[a]	1957	0.27
Marbled Murrelet	*Brachyramphus marmoratus*	P	0.205[b]	1851	0.25
Glaucous-winged Gull	*Larus glaucescens*			793	0.11
Arctic Tern	*Sterna paradisaea*	P	0.101[c]	499	0.07
Red-breasted Merganser	*M. serrator*	P	0.794[d]	413	0.06
Common Merganser	*Mergus merganser*	P	1.134[d]	355	0.05
Barrow's Goldeneye	*Bucephala islandica*			319	0.04
Harlequin Duck	*Histrionicus histrionicus*			265	0.04
Bonaparte's Gull	*L. philadelphia*	P	0.205[e]	211	0.03
Mew Gull	*L. canus*	P	0.430[f]	178	0.02

[a] Gabrielsen et al. 1987; [b] Kuletz et al. 1995; [c] Uttley et al. 1994; [d] Palmer 1976; [e] Terres 1980; [f] Ellis 1984.

Table 2: Parameters for the regression $y = mx + b$, where y is the log of field metabolic rate and x is the mass of the bird.

Source	Intercept (SE)	Slope (SE)	Mass range	Unit	N
Nagy 1987[1]	0.904 (0.187)	0.704 (0.061)	420-9440	g	15
Birt-Friesen 1989[2]					
cold-water, all seabirds	3.13 (0.03)	0.646 (0.040)	0.043-13.0	kg	16
cold-water, flapping flight	3.24 (0.05)	0.727 (0.039)	0.083-3.210	kg	8

[1] Nagy (1987) reports mass as grams rather than kilograms, and we retain his usage in this table.

[2] This author reports regressions for cold-water seabirds, and cold water seabirds using flapping flight.

Table 3: Observed feeding rates.

Species	Sample time (N)	Fry/hr	Foraging hrs/day
Black-legged Kittiwake	0:42 (9)	98.2	2.3[1]
Bonaparte's Gull	0:20 (4)	66.0	2.3
Arctic Tern	0:31 (7)	65.2	2.3

[1] Hours per day spent foraging was calculated as the time per foraging trip spent in search behavior (e.g. localized circling, plunging; 60-80 min/trip. Irons 1992) times the number of foraging trips per day. We assumed birds that made two foraging trips per day (Irons 1992) and spent 70 minutes per trip actively searching and feeding. This estimate was used for all species.

FIGURE CAPTIONS

Fig. 1: Study location. The small inset indicates the location of Prince William Sound in Alaska; the larger inset shows Esther Island relative to Prince William Sound. In the main map, Wally Noerenberg Hatchery is indicated by a star. Numbered polygons represent the count areas surveyed from a small skiff. Polygons 1-7 collectively form Lake Bay, 9-13 form Quillian Bay, and 8 and 14 form the Wells Passage count area.

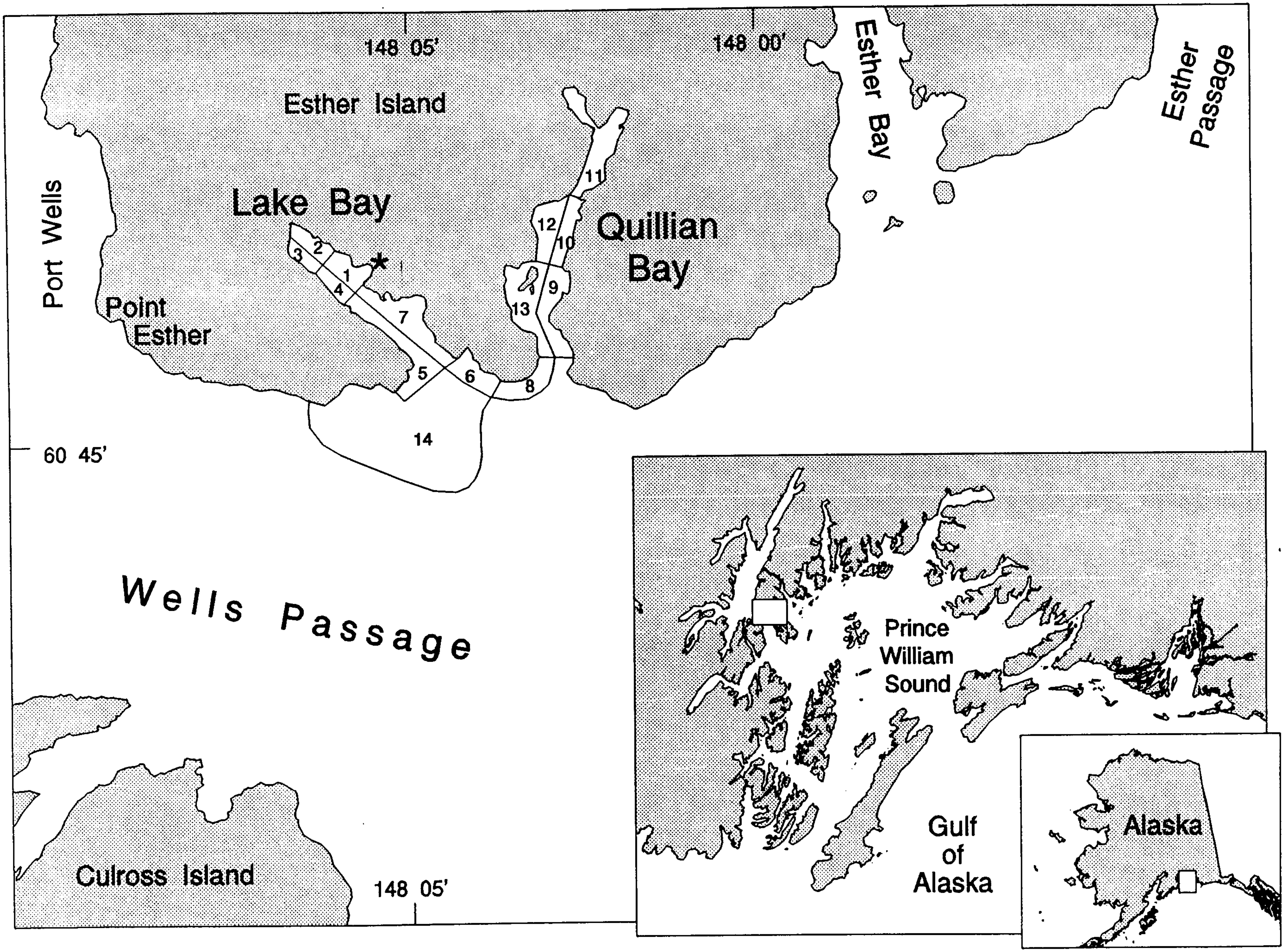
Fig. 2: Comparison of some published energetic models for seabirds. The mass regression equations and parameters are given in Table 3. Measured field metabolic rates (FMR) for Black-legged Kittiwakes (FMR equals the average of on nest and off nest measurements, Gabrielsen et al. 1987) and Arctic Terns (Uttley et al. 1994) are also plotted for comparison to predicted values. See text for a discussion of differences between the models. The species are plotted based on the body masses in Table 1 and are: Arctic Tern (ARTE), Marbled Murrelet (MAMU), Bonaparte's Gull (BOGU), Black-legged Kittiwake (BLKI), Mew Gull (MEGU), Red-breasted Merganser (RBME), and Common Merganser (COME).

Fig. 3: Numbers of fry remaining in front of the hatchery under two estimates of movement rates. We assumed that either 2.5% (low movement) or 50% (high movement) of the fry in the area leave each day. The high movement scenario was equivalent to assuming an average movement rate of two kilometers per day. Note that while this parameter had a large effect on the number of fry remaining in the area (left axis, boxes), the effect on the energy content of the average fry (right axis, no boxes) was much smaller.

Fig. 4: The numbers of Marbled Murrelets, Black-legged Kittiwakes, and total piscivores counted in the study area. Salmon fry release dates and numbers are shown for comparison. Note that zero on the right axis has been raised to visually separate the fry release line from the bird counts. Piscivores increased in the area in response to fry releases, and decreased when intervals between releases were longer.

Fig. 5: Comparison of per capita consumption based on observed feeding rates and energetic models.

Fig. 6: Cumulative consumption of pink and chum fry by seven species of birds from the first day of fry release to 7 June 1995, the last day that birds were counted. Consumption was based on the three energetics models listed along the x-axis, and calculated assuming both high and low fry movement rates. See text for details.


148 05'
148 00'
Esther Island
Esther Bay
Esther Passage
Port Wells
Lake Bay
Quillian Bay
Point Esther
1
2
3
4
5
6
7
8
9
10
11
12
13
14
60 45'
Wells Passage
Culross Island
148 05'
Prince William Sound
Gulf of Alaska
Alaska

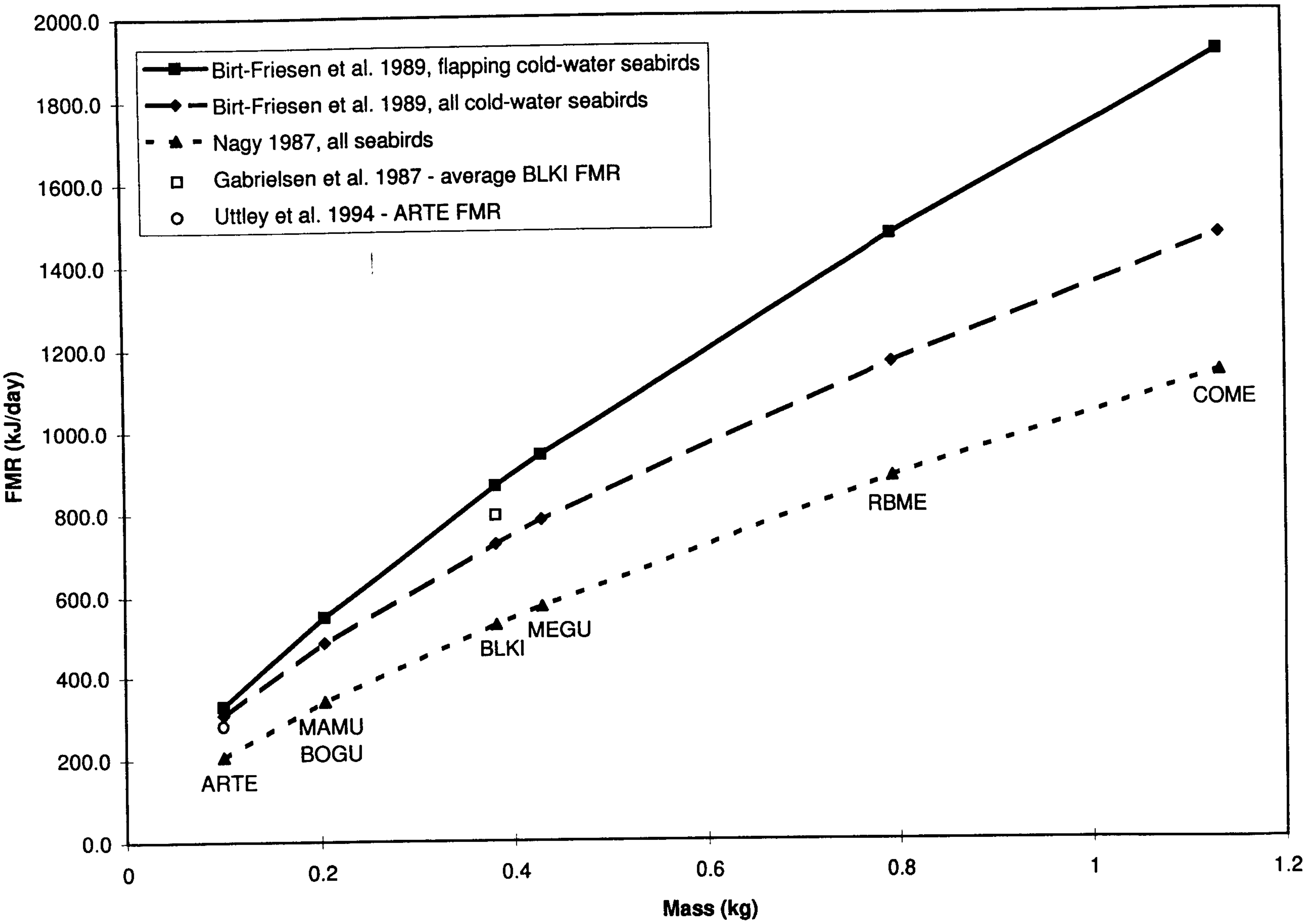
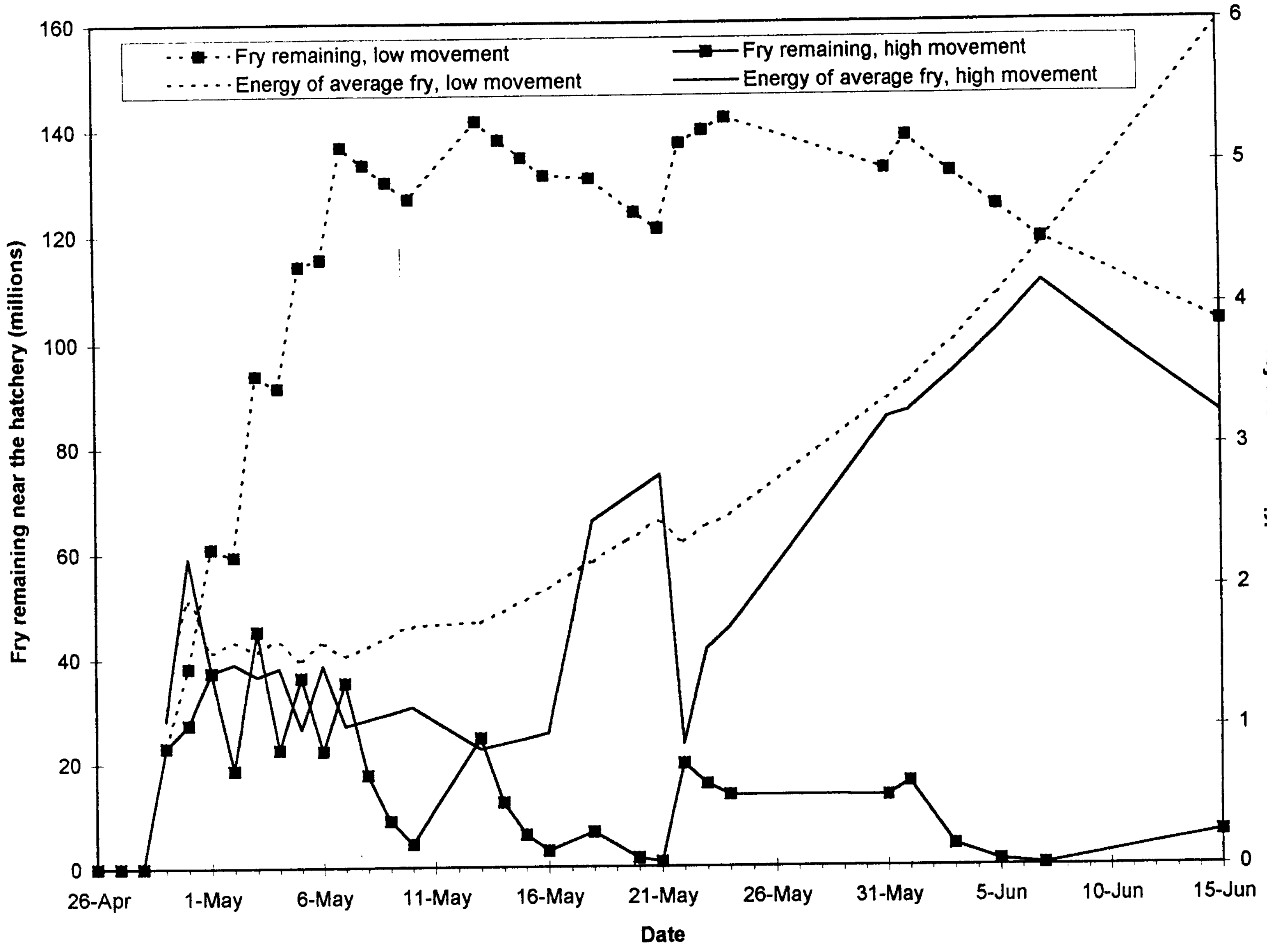
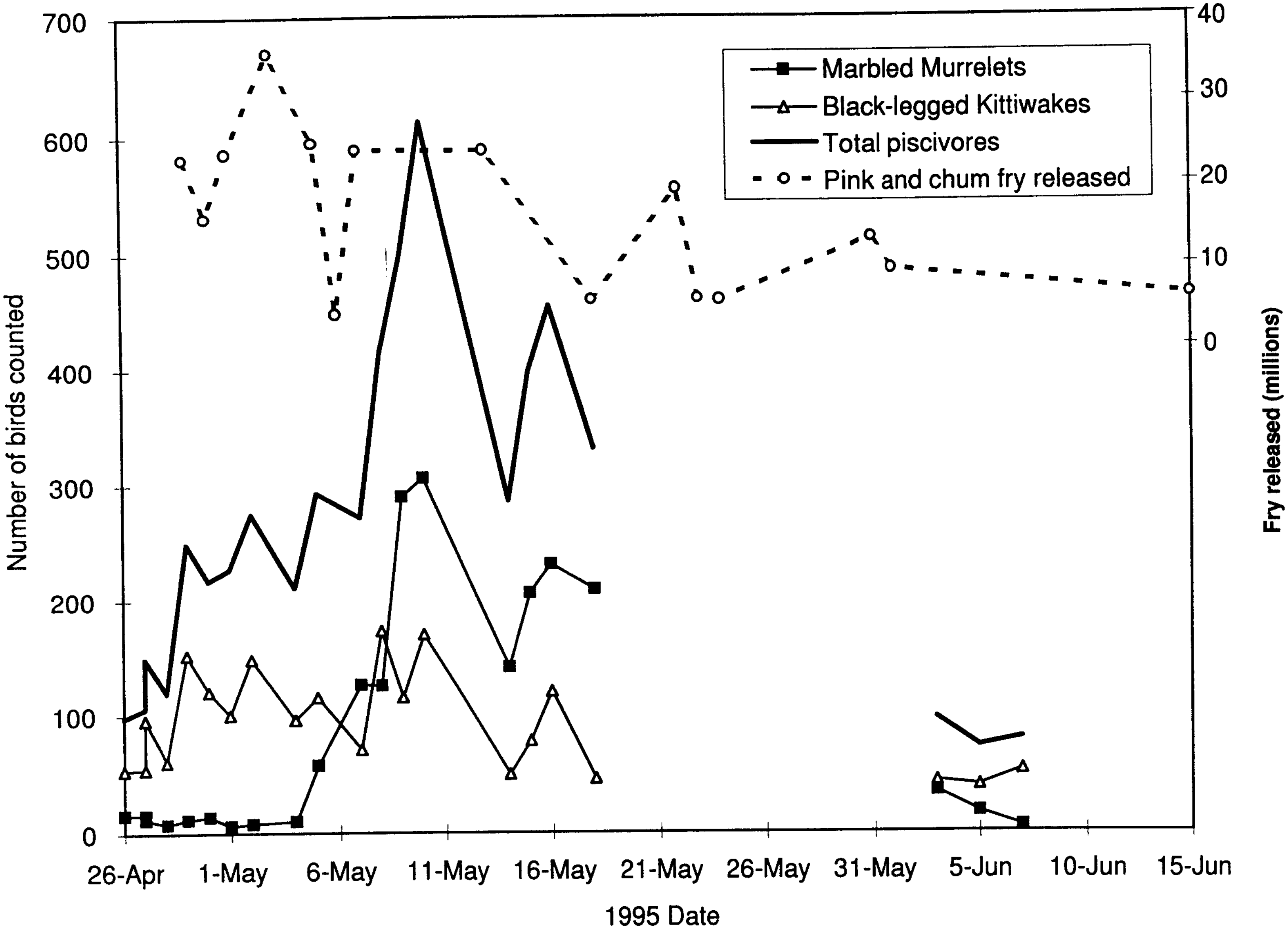
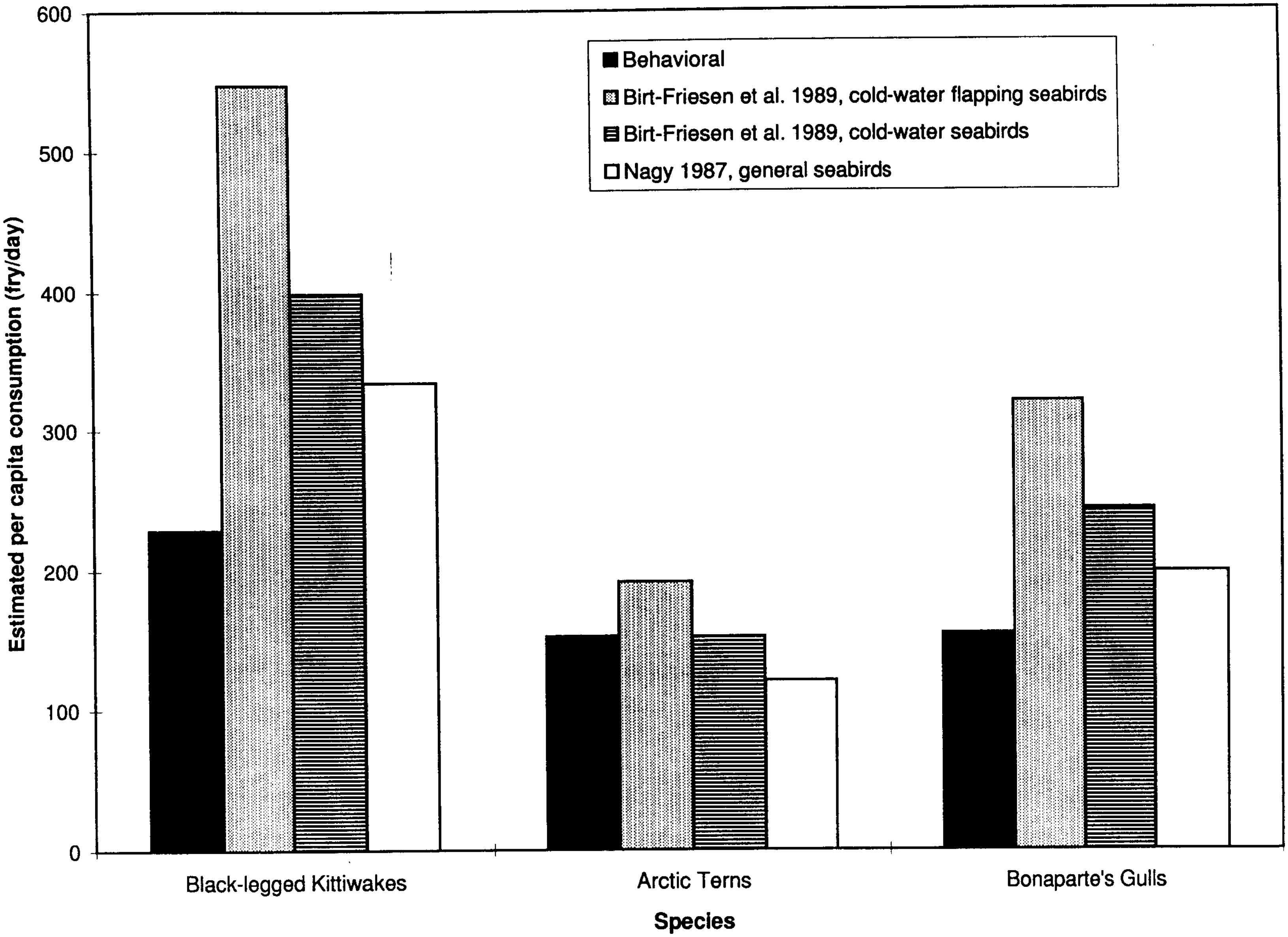

Birt-Friesen et al. 1989, flapping cold-water seabirds
Birt-Friesen et al. 1989, all cold-water seabirds
Nagy 1987, all seabirds
Gabrielsen et al. 1987 - average BLKI FMR
Uttley et al. 1994 - ARTE FMR
FMR (kJ/day)
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0
0.2
0.4
0.6
0.8
1
1.2
Mass (kg)
ARTE
MAMU
BOGU
BLKI
MEGU
RBME
COME

Fig. 5

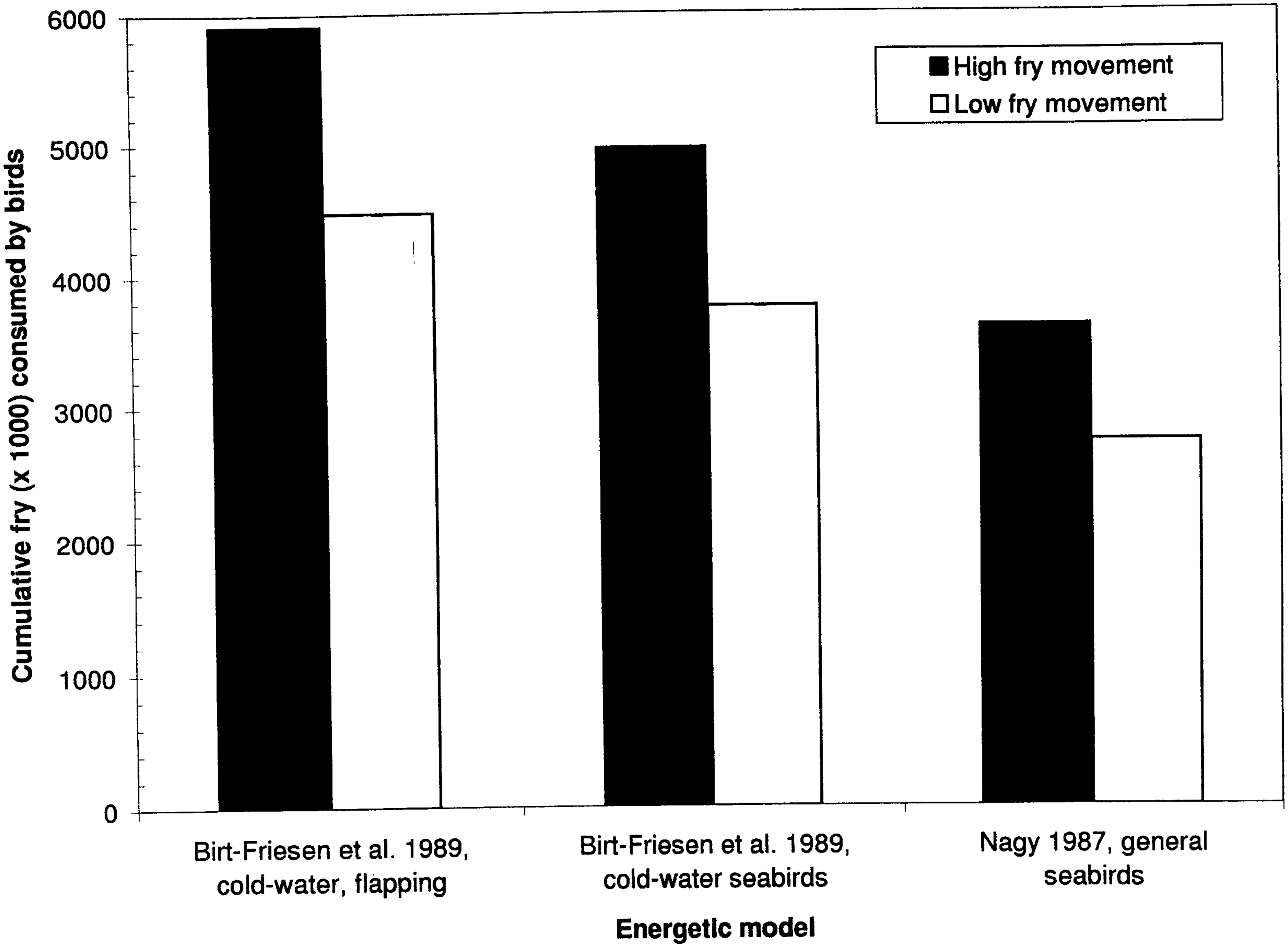


Fry remaining, low movement
Energy of average fry, low movement
Fry remaining, high movement
Energy of average fry, high movement
Fry remaining near the hatchery (millions)
160
140
120
100
80
60
40
20
0
Kj per average fry
6
5
4
3
2
1
0
26-Apr
1-May
6-May
11-May
16-May
21-May
26-May
31-May
5-Jun
10-Jun
15-Jun
Date


Marbled Murrelets
Black-legged Kittiwakes
Total piscivores
Pink and chum fry released
Number of birds counted
0
100
200
300
400
500
600
700
Fry released (millions)
0
10
20
30
40
26-Apr
1-May
6-May
11-May
16-May
21-May
26-May
31-May
5-Jun
10-Jun
15-Jun
1995 Date



600
500
400
300
200
100
0
Estimated per capita consumption (fry/day)
■ Behavioral
▩ Birt-Friesen et al. 1989, cold-water flapping seabirds
▤ Birt-Friesen et al. 1989, cold-water seabirds
☐ Nagy 1987, general seabirds
Black-legged Kittiwakes
Arctic Terns
Bonaparte's Gulls
Species



Cumulative fry (x 1000) consumed by birds
6000
5000
4000
3000
2000
1000
0
■ High fry movement
☐ Low fry movement
Birt-Friesen et al. 1989, cold-water, flapping
Birt-Friesen et al. 1989, cold-water seabirds
Nagy 1987, general seabirds
Energetic model

CHAPTER 2: Incidental species, other hatcheries, and the spatial distribution of gulls.

Methods and Results for Objectives (1) Bird aggregations, (2) Behavioral sampling, and (4) Consumption are reported in Ch. 1. Some further material for these objectives are reported here, as are the Methods and Results for objective (3) Volunteer data. Except where otherwise noted, all data was collected near Wally Noerenberg Hatchery on Esther Island.

METHODS

1) Size and composition of aggregations: All birds in Lake and Quillian Bays (Esther Is.) were counted from a small boat (as described in Ch. 1). Bird numbers were always low enough (less than 500 of any species) that precise counts could be made from the skiff without the use of photographic counting.

Birds were also censused over broader areas from aerial surveys using high-resolution video photography. Five successful survey flights were conducted, on 24 April, 1, 8, 16 May, and 3 June 1995. Two other SEA projects conducted additional ~~flights~~ using similar methods and including some of the same areas (projects 95320-Q, Avian predation on herring spawn [M.A. Bishop], and 95320-T, Juvenile herring distribution [E. Brown]). However, as of this report, data from these studies were not yet available for combined analyses, and data reported here are from this study only. Hatcheries and other parts of Prince William Sound were surveyed from a small plane equipped with a global positioning system (GPS) linked high resolution video camera. Surveys were flown at an altitude of 180 meters (600 feet). Single white birds could readily be seen and counted from the videotape filmed at this altitude. During each survey, two observers recorded all birds observed on either side of the plane out to a visual angle of about 30°. The video camera recorded a transect 200 meters wide directly under the plane while observers counted to either side of the plane to about 500 meters. Birds appearing on film were counted during playback from a small television screen and their positions were mapped. It was not possible to identify birds on videotape to species, nor to reliably see dark birds. The tapes were therefore analyzed as a sample of white birds, largely gulls.

GPS-recorded flight paths and the locations of bird flocks were entered into the geographic information system Arc/Info. Information on the distribution of fish was obtained from Prince William Sound Aquaculture Corporation (release dates, numbers, and sizes of fry reared at each hatchery) and the Alaska Department of Fish & Game (estimated tons of herring gathered for spawning at beaches, linear miles of spawn deposited). A 20 km X 20 km grid was overlaid on the study area (Fig. 1) and the linear miles of survey flight, total number of birds, cumulative hatchery fry released, and total tons of herring seen at beaches over the 7 days preceding each flight were calculated for each grid cell. ANOVAs were used to evaluate the correspondence of bird numbers per linear kilometer of survey to each of the other variables.

2) Behavior: Focal-animal sampling was conducted on individual birds in foraging flocks in or at the mouths of Lake and Quillian Bays (as described in Ch. 1).

3) Volunteer organization: Five hatcheries operate in Prince William Sound: Wally Noerenberg Hatchery on Esther Is., Lake Bay; Armin F. Koernig Hatchery on Evans Island, Sawmill Bay; Main Bay Hatchery in Main Bay; Cannery Creek Hatchery in Unakwik Inlet on Cannery Creek; and Solomon Gulch Hatchery in Valdez Arm on Solomon Gulch. Each hatchery was visited to recruit one or several volunteer staff to count and identify birds. Volunteers at each location were provided with Bushnell 8X40 binoculars, a Field Guide to the Birds of North America (National Geographic Society 1987), and a guide to local species of gulls. At each hatchery, an area was designated that could be easily observed from a point on shore. Each area included about 500 meters of shoreline and birds were counted out to 200 meters, although the dimensions of the areas varied according to the local geography. Data forms and instructions were provided. Volunteers were asked to record the birds in the count area as regularly as possible, preferably daily from April at least through the last release of fry from the hatchery. Discussions with hatchery managers and site visits by D. Scheel suggested that at least some of the volunteers did not reliably distinguish different species of birds. We therefore restricted our analyses to considering all gull species as a single group and all non-gull species as a second group.

4) Calculating consumption rates:
Detailed methods for estimating the cumulative consumption of fry by birds at the Wally Noerenberg Hatchery are given in Ch. 1.

RESULTS

Most results for Objectives (1), (2), and (4) are reported in Ch 1. Some further material for these objectives is included here, as are the results for objective (3).

1) Size and composition of aggregations
Bird censuses: Birds were surveyed on a total of 23 days. Thirty-six counts of birds were made in Lake Bay; 30 included portions of Wells Passage at the mouth of the bay (Ch. 1, Fig. 1); 24 surveys included Quillian Bay. Sixty-five bird species were represented in a total of 8,746 birds counted (Table 1). Of these, two thirds were counted in Lake Bay and one third in Quillian. Results of bird counts regarding the ten most common species of birds in the count area are reported in Ch. 1.

Aerial surveys: Five aerial surveys were flown during which bird aggregations were counted and mapped (Fig. 2-6). Total birds per kilometer of flight was higher in grid cells that contained schooling herring (ANOVA, F=7.79, $p = 0.007$) and in grid cells containing a hatchery (ANOVA, F=22.16, $p < 0.001$). In these surveys, seabird numbers declined from April through June, which was reflected in a negative correlation with the date (ANOVA, F=6.70, $p = 0.013$).

2) Behavior:

A total of 30 focal animal samples were attempted on three species of plunge-diving seabirds in mixed-species flocks: Black-legged Kittiwakes, N=15, Arctic Terns, N=10, and Bonaparte's Gulls, N=5. Of these, the birds in eight samples (total duration 38 minutes) could not be seen closely enough to observe whether fish were caught in their beaks following capture attempts. These samples were discarded from further consideration. Of the remaining 22 samples, two were discarded because the birds were not observed for at least three minutes. The remaining 20 samples were used to estimate feeding rates and daily consumption of these three species (Ch. 1).

3) Volunteer data:

Volunteers at four hatcheries made a total of 189 counts of birds (Table 2). Gulls, terns and other fish-eating birds made up most of the counts at Armin F. Koernig Hatchery (Evans Island), and Main Bay Hatchery. At Cannery Creek and Solomon Gulch, ducks and other birds were almost as common as gulls, terns and other piscivores (Table 2). At each hatchery except Main Bay, the numbers of gulls and terns increased following the first release of fry (Table 2; Fig. 7). At Main Bay, counts dipped in the week following the first fry release, but showed an overall increase from April to June (Fig. 7).

4) Calculating consumption rates: See Ch. 1 for complete results.

DISCUSSION

This report presents two main results. The first, discussed in detail in Ch. 1, is an estimate of consumption of pink and chum salmon fry in front of Wally Noerenberg Hatchery. The second is an analysis of the distribution of white seabirds (largely gulls) based on five aerial surveys over western Prince William Sound (Figs. 1-6). Gulls were associated with spawning herring and with hatchery sites.

Large numbers of gulls were present at the north end of Montague Island (Fig. 2-3), one of the major herring spawning beaches in Prince William Sound. Boat counts of birds aggregating where spawn was present indicated that most of these were Glaucous-wing Gulls gorging on spawn. Plunge-diving species that commonly feed on small fish were rare (pers. comm., M.A. Bishop. See reports of 94- and 95320-Q, Avian predation on herring spawn). However, gull numbers during all aerial surveys were not correlated with linear miles of herring spawn, but were correlated with the recent presence of schools of herring aggregated to spawn. The correlation of 'white' bird aggregations with the presence of small fish (spawning herring and hatchery locations) indicates that concentrations of forage fish have an important influence on the distribution of birds at sea during this time of the year. The variation in bird numbers that are attracted to hatchery releases each year (see Ch. 1) may be explained if birds aggregate at the best feeding sites: when available, these are the spawning migrations of herring, sandlance or other fish. When the spawning of these forage fish does not coincide with fry release or outmigration, then larger numbers of birds may be attracted to salmon fry at hatcheries and in streams. Additional data is required to test this idea; it is possible that this pattern might be documented under studies conducted by the Apex Predator Experiment group (APEX).

Gull abundances in the aerial surveys declined over the course of the study. The avian counts recorded at Wally Noerenberg Hatchery also declined in late May and early June (Ch. 1). Gulls therefore appear to leave the open shorelines of the Sound or become less visible towards the end of May. At this time, these birds are beginning their breeding seasons (Isleib & Kessel

1973) and may spend less time foraging and more time at colonies. It is also possible that gulls shift their activities further up into inlets and fjords.

LITERATURE CITED

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Table 1: Bird species list from Esther Island hatchery surveys, 1995. "Where else seen" column reflects birds surveyed outside of Lake and Quillian Bays. "Total Occurrences" reflect total number of birds observed in each bay.

				Total occurance in:	
	Common Name	Species	Where Else Seen	Lake Bay	Quillian Bay
COLO	Common Loon	*Gavia immer*		0	7
PALO	Pacific Loon	*Gavia pacifica*		3	1
RTLO	Red-throated Loon	*Gavia stellata*	Granite Bay	0	0
RNGR	Red-necked Grebe	*Podiceps grisegena*	Granite Bay, Esther Bay	2	3
HOGR	Horned Grebe	*Podiceps auritus*	Granite Bay, Esther Bay	0	3
DCCO	Double-Crested Cormorant	*Phalacrocorax auritus*	Esther Rocks, Egg Rocks	1	0
PECO	Pelagic Cormorant	*Phalacrocorax pelagicus*	Esther Rocks, Egg Rocks, Granite Bay	9	17
GTBH	Great Blue Heron	*Ardea herodias*	Esther Bay	2	0
SACR	Sandhill Crane	*Grus canadensis*	Wells Passage, migrating in April	0	0
TRSW	Trumpeter Swan	*Cygnus buccinator*	Wells Passage	0	0
CAGO	Canada Goose	*Branta canadensis*	Esther Bay, Wells & Esther Passages	0	7
MALL	Mallard	*Anas platyrhynchos*		12	45
GWTE	Green-winged Teal	*Anas crecca*		35	24
AMWI	American Wigeon	*Anas americana*		14	0
NOPI	Northern Pintail	*Anas acuta*		22	0
NOSH	Northern Shoveler	*Anas clypeata*	Forbidden Beach	0	0
	Scaup sp. (Greater or Lesser)	*Aythya spp.*	Esther Bay.	0	0
WWSC	White-winged Scoter	*Melanitta fusca*	Wells Passage, Forbidden Beach, Port Wells	0	0
SUSC	Surf Scoter	*Melanitta perspicillata*	Wells Passage, Port Wells	0	0
HADU	Harlequin Duck	*Histrionicus hitrionicus*	Esther & Egg Rocks, Esther & Granite Bay	340	23
OLDS	Oldsquaw	*Clangula hyemalis*		0	8
BAGO	Barrow's Goldeneye	*Bucephala islandica*	Esther & Granite Bay; Forbidden Beach	225	306
COGO	Common Goldeneys	*Bucephala clangula*		0	1
BUFF	Bufflehead	*Bucephala albeola*		80	3
COME	Common Merganser	*Mergus merganser*	Esther & Granite Bay; Forbidden Beach	431	104
RBME	Red-breasted Merganser	*Mergus serrator*	Esther & Granite Bay; Forbidden Beach	88	350
BLOY	Black Oystercatcher	*Haematopus bachmani*	Esther & Granite Bay; Esther & Egg Rocks	0	0
WHIM	Whimbrel	*Numenius phaeopus*		0	3
GRYE	Greater Yellowlegs	*Tringa melanoleuca*		0	2
SPSA	Spotted Sandpiper	*Actitis macularia*		0	3
WATA	Wandering Tattler	*Heteroscelus incanus*		3	1
DOSP	Unidentified Dowicher	*Limnodromus spp.*		2	2
LESA	Least Sandpiper	*Calidris minutilla*	At the hatchery	3	0
BASA	Baird's Sandpiper	*Calidris bairdii*	At the hatchery	1	0
PAJA	Parasitic Jaeger	*Stercorarius parasiticus*	Forbidden Beach	0	0
BOGU	Bonaparte's Gull	*Larus philadelphia*	Forbidden Beach	406	2
MEGU	Mew Gull	*Larus canus*	Esther & Granite Bay; Forbidden Beach	189	59

	Common Name	Species	Where Else Seen	Total occurance in: Lake Bay	 Quillian Bay
HEGU	Herring Gull	*Larus argentatus*		14	0
GWGU	Glaucous-winged Gull	*Larus gaucescens*	Everywhere	1120	126
BLKI	Black-legged Kittiwake	*Rissa tridactyla*	Everywhere	1608	599
ARTE	Arctic Tern	*Sterna paradisaea*	Granite Bay	397	50
PIGU	Pigeon Guillemot	*Cepphus columba*	Esther & Granite Bay; Forbidden Beach	44	41
MAMU	Marbled Murrelet	*Brachyramphus marmoratus*	Everywhere	673	1029
KIMU	Kittlitz's Murrelet	*Brachyramphus brevirostris*	Possible sighting, Barry Arm.	0	0
BAEA	Bald Eagle	*Haliaeetus leucocephalus*	Esther & Granite Bay; Forbidden Beach	68	15
NOHA	Northern Harrier	*Circus cyaneus*		0	1
RUHU	Rufous Hummingbird	*Selasphorus rufus*	At the hatchery	1	0
BEKI	Belted Kingfisher	*Ceryle alcyon*		3	0
STJA	Steller's Jay	*Cyanocitta stelleri*	Wooded shores	No count	No count
NWCR	Northwestern Crow	*Corvus caurinus*	Wooded shores, intertidal	No count	No count
CORA	Common Raven	*Corus corax*	Wooded shores	No count	No count
RCKI	Ruby-crowned Kinglet	*Regulus calendula*	At the hatchery	No count	No count
GCTH	Grey-cheeked Thrush	*Catharus minimus*	By call only	Heard	Heard
HETH	Hermit Thrush	*Catharus guttatus*	By call only	Heard	Heard
VATH	Varied Thrush	*Ixoreus naevius*	Wooded shores, by call	No count	No count
AMRO	American Robin	*Turdus migratorius*		0	1
WAPI	Water Pipit	*Anthus spinoletta*		4	0
AMDI	American Dipper	*Cinclus mexicanus*	By streams	2	1
OCWA	Orange-crowned Warbler	*Vermivora celata*	Shoreline shrubs, by call	No count	No count
WIWA	Wilson's Warbler	*Wilsonia pusilla*	Shoreline shrubs, by call	No count	No count
SASP	Savannah Sparrow	*Passerculus sandwichensis*	At the hatchery	6	0
DEJU	Dark-eyed Junco	*Junco hyemalis*	Wooded shores, by call	No count	No count
FOSP	Fox Sparrow	*Passerella iliaca*	At the hatchery	3	0
PISI	Pine Siskin	*Carduelis pinus*	Wooded shores, by call	No count	No count
CORE	Common Redpoll	*Carduelis flammea*	Wooded shores	No count	No count
SEOT	Sea Otter	*Enhydra lutris*	Everywhere	19	12
RIOT	River Otter	*lutra canadensis*	Wooded shores, Lake & Quillian; net pens	7	5
	Mink	*Mustela vison*	Wooded shores, Lake & Quillian; net pens	2	1
STSL	Steller's Sea Lion	*Eumetopias jubatus*	Well's Passage, Forbidden Beach	9	5
HASE	Harbor Seal	*Phoca vitulina*	Granite Bay	9	13
DAPO	Dall's Porpoise	*Phocoenoides dalli*	Well's Passage	No count	No count
HAPO	Harbor Porpoise	*Phocoena phocoena*	Well's Passage	No count	No count
	Minke, Humpback, and Killer whales also reported inside Lake Bay.			No count	No count
	Black Bear		Granite & Quillian Bay	No count	No count

Table 2: Volunteer Bird Count Data

Hatcheries	Earliest Fry Release Date	Total Days[1]	Total Gulls & Terns[2]	Total Fish-eating Birds[3]	Others[4]
Armin F. Koernig	25-Apr-95	33	534	180	300
Cannery Creek	29-Apr-95	30	992	37	1036
Main Bay	30-Apr-95	99	1363	373	1110
Solomon Gulch	2-May-95	27	85	21	82
Totals		189	2974	611	2528

[1] Total days data was collected by volunteers at hatcheries listed above.

[2] Species of gull consisted of: Bonaparte's, Mew, Herring, Glaucous-winged, Glaucous, Black-legged Kittiwake, Sabine's and unknown Gulls. Tern species were: Caspian's, Arctic, Aleutian, and Common Terns.

[3] Species list for fish-eating birds: Pelagic and unidentified Cormorant, Great Blue Heron, Common, Red-breasted, and unidentified Merganser, Common, and unidentified Murre, Pigeon Guillemot, Marbled and unidentified Murrelet and unidentified Brachyramphus.

[4] Other bird species included in data: Common and Red-throated Loon, Common, Barrow's and unidentified Goldeneyes, Bufflehead, Bald Eagle, Belted Kingfisher, Black Oystercatcher, Mallard, American Wigeon, Leach's Storm-petrel, Northern Pintail, Canada Goose, Green-winged Teal, Lesser and Greater Yellowlegs, , Whimbrel, Greater Scaup, Gadwall, Solitary and Least Sandpiper, unidentified Dabbling Duck, Black, White-winged and Surf Scoters, Common Raven, unidentified Grebe, Wandering Tattler, Sandhill Crane, and Northwestern Crow.

FIGURE CAPTIONS

Figure 1: Twenty kilometer by twenty kilometer grid overlaid on Prince William Sound for analyses of aerial survey data.

Figure 2: Locations of birds visible from the air (gulls and large ducks) on 24 April 1995 (prior to release of hatchery-reared fry). The flight path is indicated by the solid black line. The number of birds is indicated by the size of the spot marker. Bird locations were recorded by a computer-linked global positioning system. Birds were counted by observers and the numbers were verified by counting from high-resolution videotape.

Figure 3: Locations of birds, 1 May 1995 (after fry releases had begun). Details as in Figure 2.

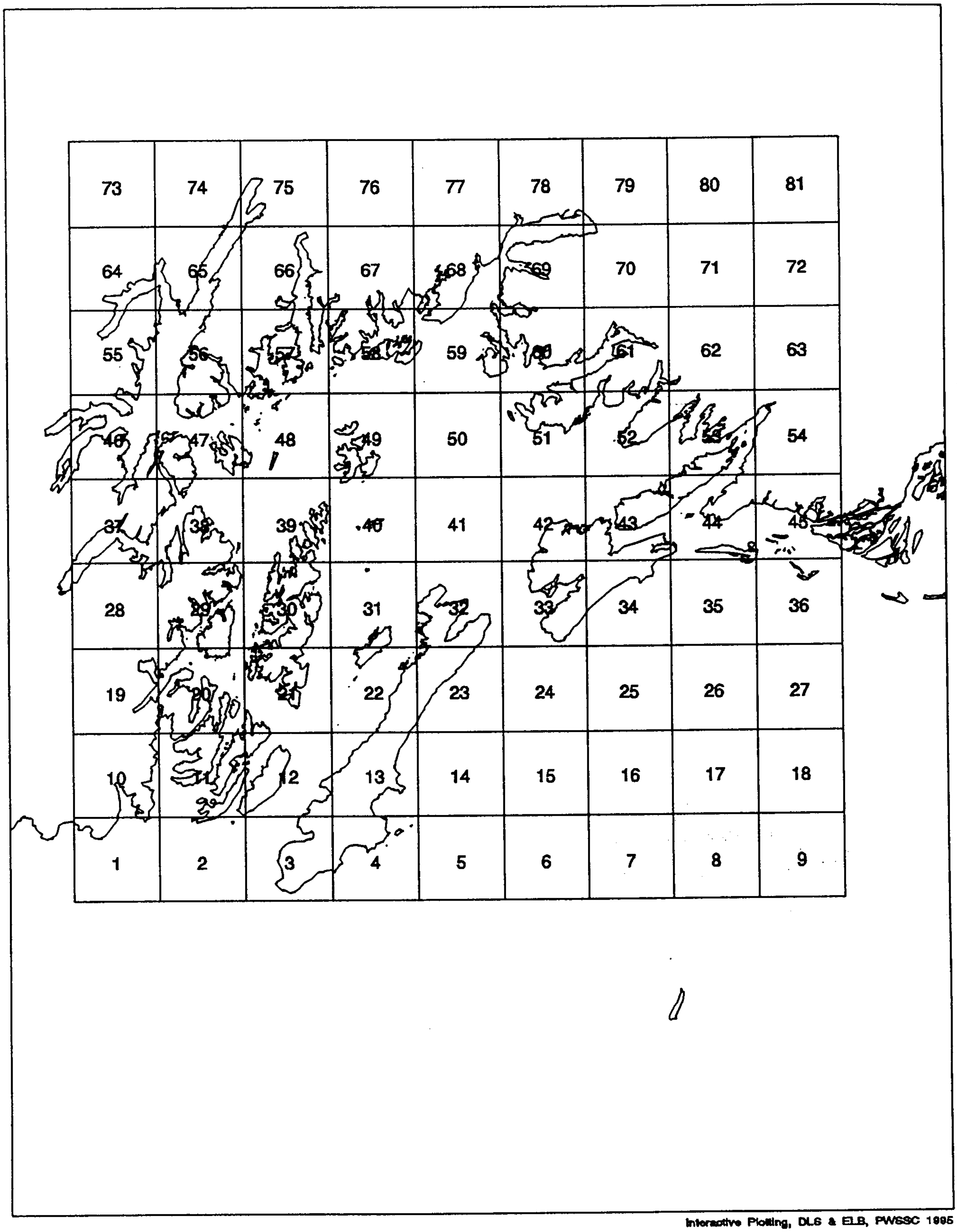
Figure 4: Locations of birds, 8 May 1995. Details as in Figure 2.

Figure 5: Locations of birds, 16 May 1995. Details as in Figure 2.

Figure 6: Locations of birds, 3 June 1995. Details as in Figure 2.

Figure 7: The number of gulls and terns counted by volunteers in front of four hatcheries in Prince William Sound. The hatcheries are Armin F. Koernig (AFK), Cannery Creek (CCH), Main Bay (Main), and Solomon Gulch (SGH). Numbers presented are averages over all counts in a given calendar week. Numbers were generally low prior to fry releases (compare Table 2), however, increases in counts did not closely correspond with release periods.

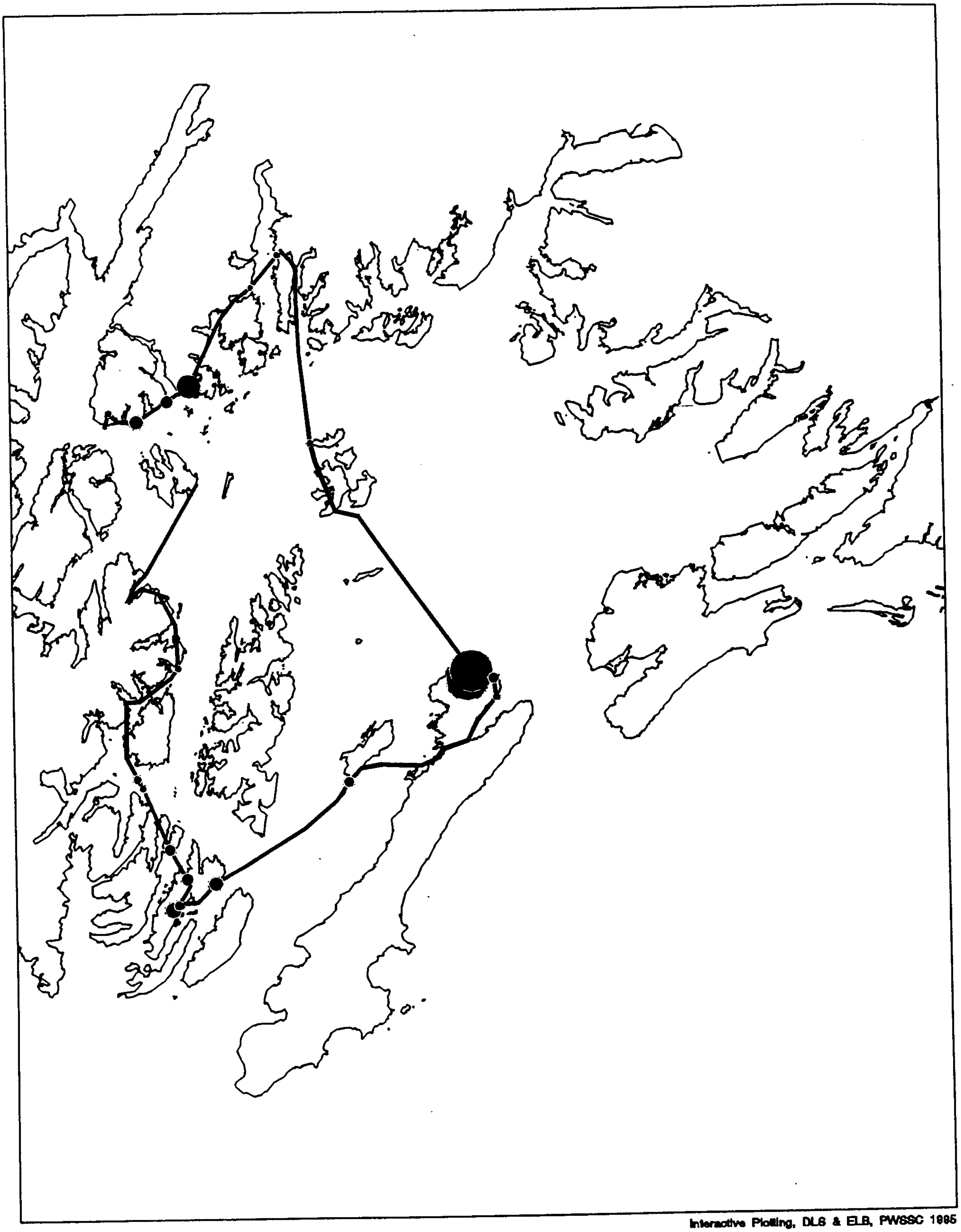
FIG. 1



Interactive Plotting, DLS & ELB, PWSSC 1995

Analysis grid and grid numbers. Each cell is 20 by 20 kilometers.

FIG. 2



Interactive Plotting, DLS & ELB, PWSSC 1995

24-Apr-95; Smallest point indicates five birds

FIG. 3

Interactive Plotting, DLS & ELB, PWSSC 1995

01-May-95; Smallest point indicates five birds.

FIG. 4

Interactive Plotting, DLS & ELB, PWSSC 1995

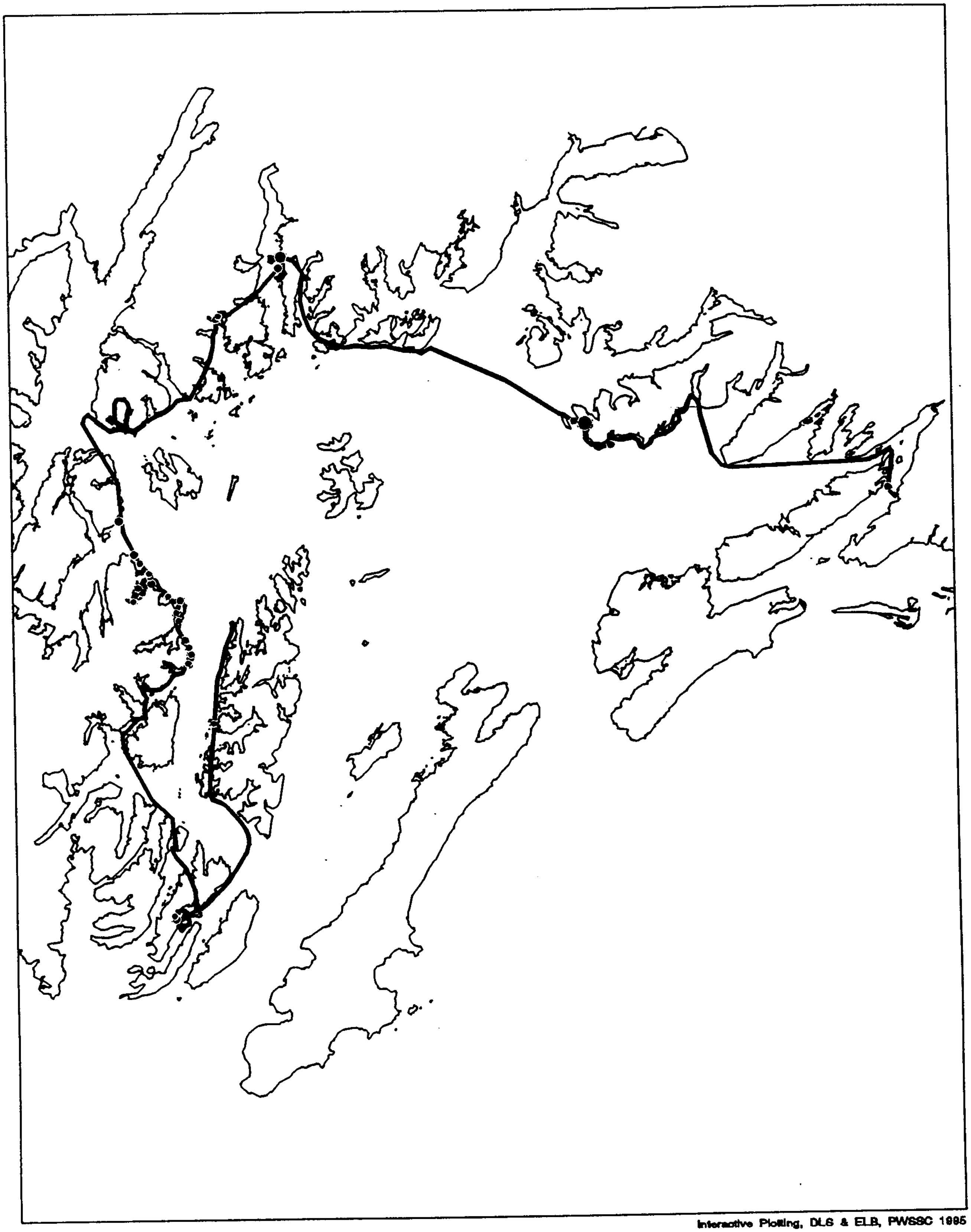
08-May-95; Smallest point indicates five birds.

FIG. 5

Interactive Plotting, DLS & ELB, PWSSC 1995

16-May-95; Smallest point indicates five birds.

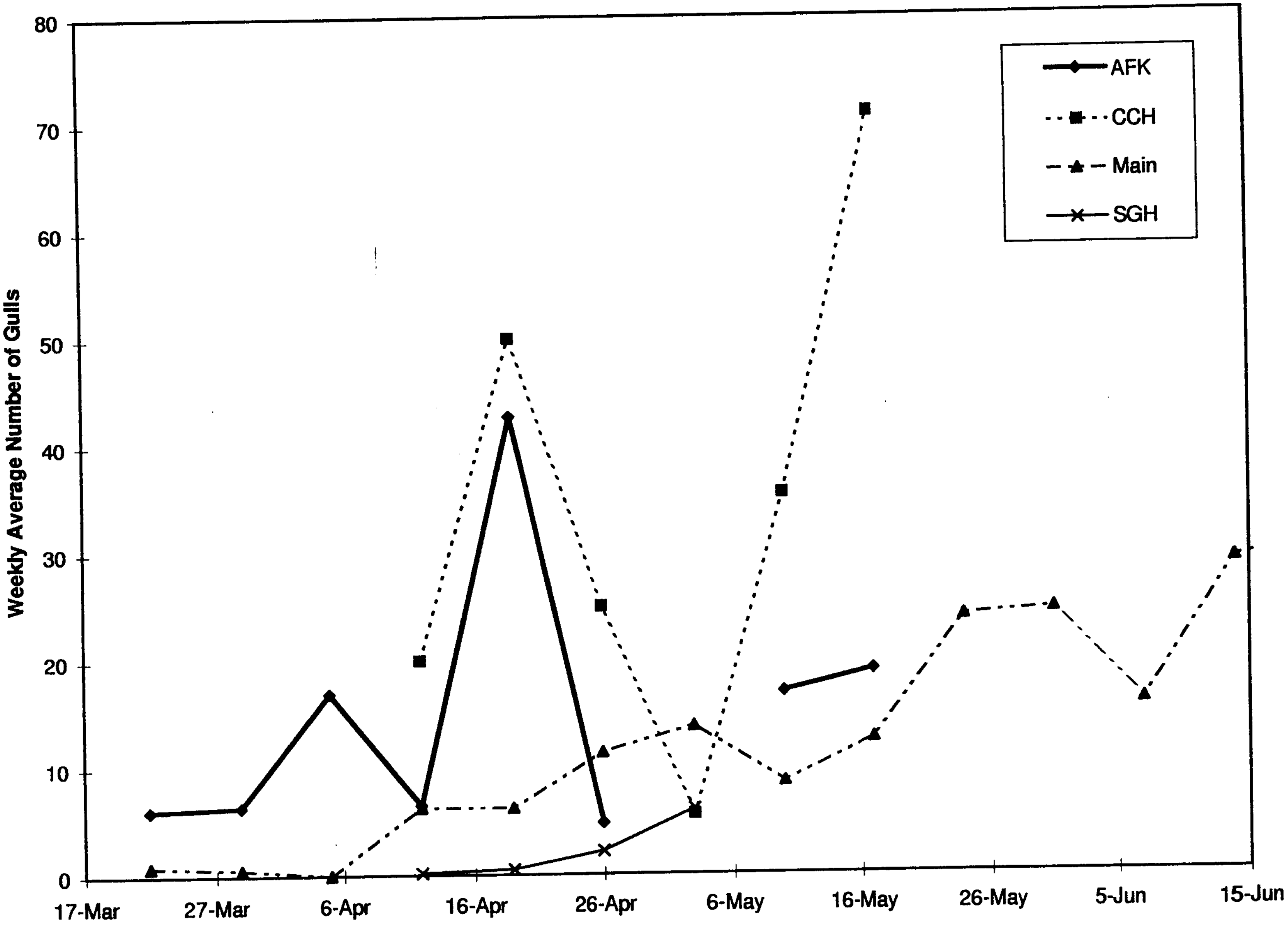
FIG. 6



Interactive Plotting, DLS & ELB, PWSSC 1995

03-June-95; Smallest point indicates five birds.

FIG. 7


Weekly Average Number of Gulls
80
70
60
50
40
30
20
10
0
17-Mar
27-Mar
6-Apr
16-Apr
26-Apr
6-May
16-May
26-May
5-Jun
15-Jun
AFK
CCH
Main
SGH

CONCLUSIONS

This project is one part of the Sound Ecosystem Assessment program's effort to identify major predators on pink salmon fry, the magnitude of predation, and the variability in predation over time and space. Seabirds consumed 1.1-2.4% of fry released from Wally Noerenberg Hatchery in 1995. These results provide a good starting point for comparison of the magnitude of predation by birds to that of the other major predators (e.g. walleye pollock and squid). Data on fish that prey on pink salmon fry are provided by the SEA project, Juvenile Salmon and Herring Integration. We suggest that the timing of salmon release (or outmigration) relative to that of spawning migrations by herring and other forage fish may determine the magnitude of bird aggregations that feed on salmon fry.

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