Exxon Valdez Oil Spill
Restoration Project Annual Report

The Factors That Limit Seabird Recovery In The EVOS Study Area: A Modeling Approach

Restoration Project 97163Q
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Study History: The project effort was initiated in February 1997 as a new project. Field work has not been a direct component of this project, which relies on the data gathered by all other APEX projects as well as data in the literature. In a sense, all APEX principle investigators are part of Restoration Project 97163Q. By the nature of our work --- inter-relating the data gathered by other investigators in APEX --- we, generally, are one year behind the other APEX projects.

Abstract: We use mathematical models to assess ways in which food supply could be affecting recovery of seabirds in the EVOS study area. Our intent is to test the degree to which food limitation could be affecting recovery, indicate the mechanisms by which this could come about, and identify the scale at which interactions are occurring between food availability and the species and colonies being studied by APEX. In the first year of effort we concentrated on acquiring and formatting data. We formatted fish availability data (from hyroacoustic surveys and aerial fish-school spotting) and integrated it spatially with foraging data for Black-legged Kittiwakes. We explored the feasibility of working with Pigeon Guillemots, as well, but the available data proved to be inadequate, although in the future this is likely to change. The models that we were successful in developing compared kittiwake foraging effort, using data gathered by APEX component B, G and E, and prey availability, from APEX component A and a SEA component. Best correspondence existed between kittiwake foraging and aerial spotting of fish schools. Successful foraging did relate to breeding productivity. Thus, we developed a demographic model as well. Additional work is required, but the modeling indicated that foraging activity during summer can affect population growth in the Black-legged Kittiwake.

Key Words: *Exxon Valdez*, Pigeon Guillemots, Black-legged Kittiwakes, foraging effort, prey availability, population growth, mathematical modeling.

Project Data: (will be addressed in the final report)

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Executive Summary

We used mathematical models to assess ways in which food supply could be affecting recovery of seabirds in the EVOS study area. Thus, we addressed the main APEX (Alaska Predator Experiment) hypothesis that food supply is limiting recovery of certain avian populations from the *Exxon Valdez* oil spill. Data inputs comprised information from the field components of APEX supplemented with data published elsewhere. We confined our effort in 1997 to the Black-legged Kittiwake, the species in Prince William Sound for which data were sufficient for analysis. We found that foraging activity was affected by food availability, as determined from fish school assessments (hydroacoustic, aerial spotting). In turn, breeding success was related to foraging effort. Finally, we modeled population growth showing how it is affected by breeding success.

Introduction

The general hypothesis of the APEX project is that a change in the relative abundance of forage fish species has prevented recovery of injured avian populations in Prince William Sound; within this general hypothesis a series of 10 working hypotheses are being investigated by the various APEX components (see Duffy 1996, p. 6-7). The data being collected to test these hypotheses differ in temporal and spatial scale. Some additional data at the time scale of decades exist. However, most of the data are at much smaller scales than the general hypothesis, which is at the scale of decades (time for recovery in long-lived species) and at the spatial scale of the entire sound. Statistical inference can be used to bridge some but not all of this gap. We discussed how this task will be undertaken, in a conceptual way, in our previous Annual Report (Ainley et al. 1997). Our approach integrates the available information, bridges the gap from data to the hypothesis, and identifies variables that need to be linked. The model output allows avian recovery rates to be evaluated in relation to prey availability, using data and knowledge gathered for this ecosystem.

After exploring the data available to us, i.e. those from the 1996 and 1997 field seasons, it became clear that the formulation of our models would be most successful for the Black-legged Kittiwake (*Rissa tridactyla*) in Prince William Sound (PWS). We sought to relate the kittiwake data --- reproductive success as well as foraging effort --- to the availability of forage fish.

Objectives

Hypotheses to be evaluated by mathematical modeling using existing data, under the null hypothesis:

1. Annual survivorship, age of first breeding, foraging range, feeding frequency of chicks, and reproductive success in Black-legged Kittiwakes are not related to food availability.

2. No differences in 1 will be evident in pre- and post-spill comparisons, where possible.

Methods

Foraging effort

We began with the foraging effort data compiled by APEX Project 97163E
(David Irons, Robert Suryan and Jeb Benson). Data were available for 3 years: 1995,
1996 and 1997; and for 3 kittiwake colonies: Icy Bay, Eleanor Is and Shoup Bay; but not
for all years and all colonies. Useable data were available for Shoup and Eleanor in 1995,
Eleanor and Icy in 1996, and all three in 1997. The data were collected by following
radio-tagged individuals in a boat and recording position and behavior, as well as other
data periodically. More details on data collection are contained in Irons et al. (1997). In
the present report, we consider 1996 and 1997 data. Data acquisition occurred from
about 3 July through 10 August each year.

The data were provided to us in ASCII format. These were processed and loaded
into CAMRIS by computing the rate of movement (km/hr) between each pair of
sequential observations of kittiwakes and assigning that rate to the latitude/longitude
midpoint of the pair. Points representing intervals of slow movement were overlaid on a
map of PWS. Slow movement was considered to be foraging. We placed a 1 km grid
over the sound and counted the number of slow-movement points occurring in each grid
cell. A binary search procedure was then used to find the density isopleths that would
contain 85%, 90% and 95% of these points. In other words, for example, the 90%
isopleth contained the minimum area of 90% of the foraging activity. These regions were
termed "foraging grounds" and were assumed to be equivalent to "patches" in the
traditional sense of optimal foraging theory. Note that we could have used the actual
foraging observations to define the foraging grounds and would have gotten similar
results. Using the movement rates instead of the observations helped to compensate for
areas where the kittiwakes search for food but actually find nothing on which to feed, and
also allows us to compute the feeding rate, i.e. the number of feeding behaviors per unit
time while in the patch. Using speed to define the patch and then using behavioral
observations to define feeding rates avoids circularity.

Fish abundance

Fish availability was based either on acoustic estimates of fish biomass or on
aerial transects in which schools of forage fish were tallied. First, we analyzed the
relationship between acoustic biomass and kittiwake foraging activity. Methodology for
acoustic biomass estimation is contained in the report by Haldorson et al. (1997).
Basically the acoustic data are the integration of acoustic signal strength across all depth
strata, and presumably are an index of fish abundance. Surveys were done in each of the
three regions of PWS (vicinity of Shoup Bay, Eleanor Island and Icy Bay) during 5-6 d
periods from late July through the first week of August. Data were summarized into
standard transects about 0.7 km in length. These data, too, were entered into CAMRIS.

Next, we analyzed the relationship between the prevalence of fish schools, as spotted from aircraft, and kittiwake foraging activity. Evelyn Brown, working in the SEA program, conducted low level (200 m elevation) surveys of PWS several times during the summer. All shorelines in the Sound were over-flown. Fish schools were spotted and identified from the air, and each school was measured to determine major and minor axis lengths using a calibrated cylinder. The product of the axes lengths provided an index of school size. Forage fish were defined as herring (*Clupea harengus*), capelin (*Mallotus vilosus*), sandlance (*Ammodytes hexapterus*), salmon (*Onchorhyncus* spp.), walleye pollock (*Theragra chalcogramma*), or unidentified forage fish. Surveys were done in 1995 (9-12 June, 9-28 July, 2-22 August, 4 October), 1996 (16-24 April, 9-14 May, 10-15 June, 2-21 July, and 1-6 Aug) and in 1997 (12-21 June, 9-25 July).

Foraging grounds versus fish abundance

We looked to see if kittiwake foraging behaviors were related to fish biomass for the 1996 results (1997 data only recently have become available). A 10-km grid was laid over PWS. The number of foraging behaviors in each cell were regressed against the mean acoustic biomass in the cell.

Similarly, we regressed the number of foraging behaviors per 10-km grid cell on the sum of the axes products for each forage fish school spotted from the air within each 10-km block.

Demography

Foraging trip time was used as an indirect measure of foraging success, i.e. a short trip was assumed to be more successful than a long, drawn out trip. We used a regression model to predict the deviation from mean colony breeding performance (chicks fledged per pair) resulting from foraging trip time. Each colony's "colony effect" (e.g., a sum of peculiarities characterizing each, e.g. predation, weather etc) was normalized by dividing annual productivity at each by the average productivity. Breeding productivity data were taken from Irons et al. (1997, unpubl.).

A demographic model, using the breeding productivity data mentioned above and other demographic rate data from Suryan and Irons (ms), explored the relationship of whether foraging trip time, as it affected productivity, could affect colony growth.

Results and Discussion

Kittiwake foraging and fish availability

The kittiwake movement data supplied by Irons et al. were divided into two sets, one ≤ 25 km/hr and the other >25 km/hour. Plotting the results showed clusters of slow movements interspersed with sequences of more rapid movement (Figure 1, showing 1996 data). Moreover, using 1997 results, when a plot of movement data was overlaid with a plot of actual observations of feeding behaviors, the clustering of movement and foraging behavior showed close correspondence (Figure 2). Actual foraging behavior

was defined as any of the following behaviors: BF - Back and forth flight or circling; PD - Plunge dive; SF - Surface feed; SW - Swoop. Therefore, we were content that the movement data were a good proxy for foraging. We next used 1996 movement data to identify foraging grounds (or patches). We chose the 90% of slow-movement points to define foraging grounds.

Having defined the foraging patches, we had to determine why kittiwakes visited the ones that they did and why they stayed as long as they did at each. Traditional optimal foraging theory states that they should visit nearer patches more frequently, depleting them so that the foraging rate near the colony (i.e. feeding as compared to commuting) takes relatively longer than it would if they foraged further away. At a distance from the colony, the feeding rate should be high to compensate for the larger commute time. Therefore, foraging rate should be correlated with distance: long commute, high feeding rate: short commute low feeding rate. This was not borne out by the data (Figure 3). While this is not proof that kittiwakes are not taking up food more rapidly in distant patches, it is reasonable to assume that the rate of food uptake is proportional to the rate of feeding behaviors. What we need to be able to predict is the visitation sequence of patches, and the time spent in each one. The visitation sequence, probably, is essentially a nearest-neighbor search. This may be the subject of future investigation.

More difficult to determine is why patches were located where they were and why kittiwakes spent as long as they did in them. This is where we get into the relationship between measures of fish abundance and foraging activity. If we could define the location and quality of patches based on the fish data, we could go all the way from a hypothetical or real distribution of fish abundance to the simulation of a foraging bout, including the amount of time that the trip should require.

We plotted the fish acoustic data (biomass per unit area) against the aerial spotting data (Figure 4). Unfortunately, the correlation was very weak or non-existent. Whether or not a lack of synopticity in the two surveys explains the lack of correspondence remains to be seen. Neither was there a correlation between kittiwake foraging grounds and the acoustic data (Figure 5). Why this was so is not clear to us.

We next plotted the aerial spotting data of fish schools with the kittiwake foraging grounds (Figure 6). Visually, the correspondence looked promising. We accumulated the data on the estimated area of schools and frequency of foraging activities into grids of 2.5, 5.0, and 10.0 km. The regression coefficients between the number of bird foraging behaviors and the total areas of fish schools were as follows (**, p<0.001):

	6.25 km^2	25 km^2	100 km^2
1995	.0003	-.0147	.0958
1996	-.0031	.0137	.0238
1997	.0004	.2449**	.2194**

The correlation coefficients improved as the spatial scale of the comparison increased. In 1997, when kittiwake data were the most complete, the correlation was highly significant. We consider this a very good fit for a non-synoptic (not concurrent) bird/fish relationship, especially for kittiwakes. Why there was much less correspondence during the other years remains a puzzle. In the two earlier years, although the period when the radio telemetry was underway was covered by the fish-school spotting, there was also a good deal of spotting done outside of the radio telemetry period (see Methods, above). Perhaps this explains the discrepancy. Another possibility is that kittiwakes were keying on schools of particular forage fish species composition. We are working on this.

Demography

We linked foraging success to demographic output by looking at breeding productivity (data from Irons et al. 1997, unpubl.). Foraging success was equated to trip duration, for which data are available from Irons et al. for Shoup, Eleanor and Icy Bay colonies in 1995, 1996 and 1997. Thus, the choice to use foraging trip time was a practical one of availability. Regressing productivity on trip time yielded no relationship. But, assuming that each colony has some special attributes that make it generally good or bad relative to other colonies (e.g., exposure to prevailing winds or storms, predation, etc.), we controlled for this by dividing productivity of each colony for each year by the mean productivity for that colony. Thereby, "colony effect", was normalized. As a result, we obtained a significant or, at worst, near-significant relationship. A standard regression model yielded a coefficient p-value of 0.058; a stepwise (threshold) model) gave a value of 0.033.

We constructed a preliminary demographic model to examine the link between food supply and colony growth rate. It seems that all demographic models dealing with seabirds are "preliminary" owing to the difficulty in acquiring the necessary data and the long time span required to accumulate them. With the acquisition of data each year, in an on-going project such as that on kittiwakes in PWS, the model can be revised. For our model, trip time was used to predict the per capita productivity using the relationship above. Demographic variables, other than productivity, are from Suryan and Irons (ms in prep) as follows:

Age at first breeding	5 y
Survivorship to breeding age:	0.567
Adult survival (>5yrs):	0.922
Probability of breeding:	0.936

Using these values gives the following results:

Foraging Trip Duration	Per Capita Productivity	Rate of Population Increase
1 hr	0.271	1.063
2	0.250	1.054
3	0.229	1.046
4	0.208	1.037
5	0.188	1.028
6	0.167	1.018
7	0.146	1.008
8	0.125	0.997
9	0.104	0.986
10	0.083	0.975

These results predict that at between 7 and 8 hours trip duration an average colony of kittiwakes in Prince William Sound, under current conditions, will begin to decline. This needs to be adjusted on a per colony basis for historic colony productivity, an adjustment that may be possible in the future.

The next question is, What is the relationship between food supply and trip duration? It is not primarily distance. Straight flight accounts for a relatively small proportion of the trip time. So, most likely it is the feeding rate. What is the relationship between feeding rate and food supply? The data to answer such a question may not, at present, be available.

Conclusions

We spent our first year collecting and formatting data from several sources, and then exploring the strengths of statistical relationships between them. The next years of data analysis should be much easier and more fruitful. Nevertheless, we have determined that food supply during the chick-provisioning period can explain, at least in part, colony growth in the Black-legged Kittiwake. Thus, the main APEX hypothesis appears to be testable and appears to be valid. The degree to which other factors might explain colony growth (e.g. emigration, recruitment) will also have to be considered.

Acknowledgments

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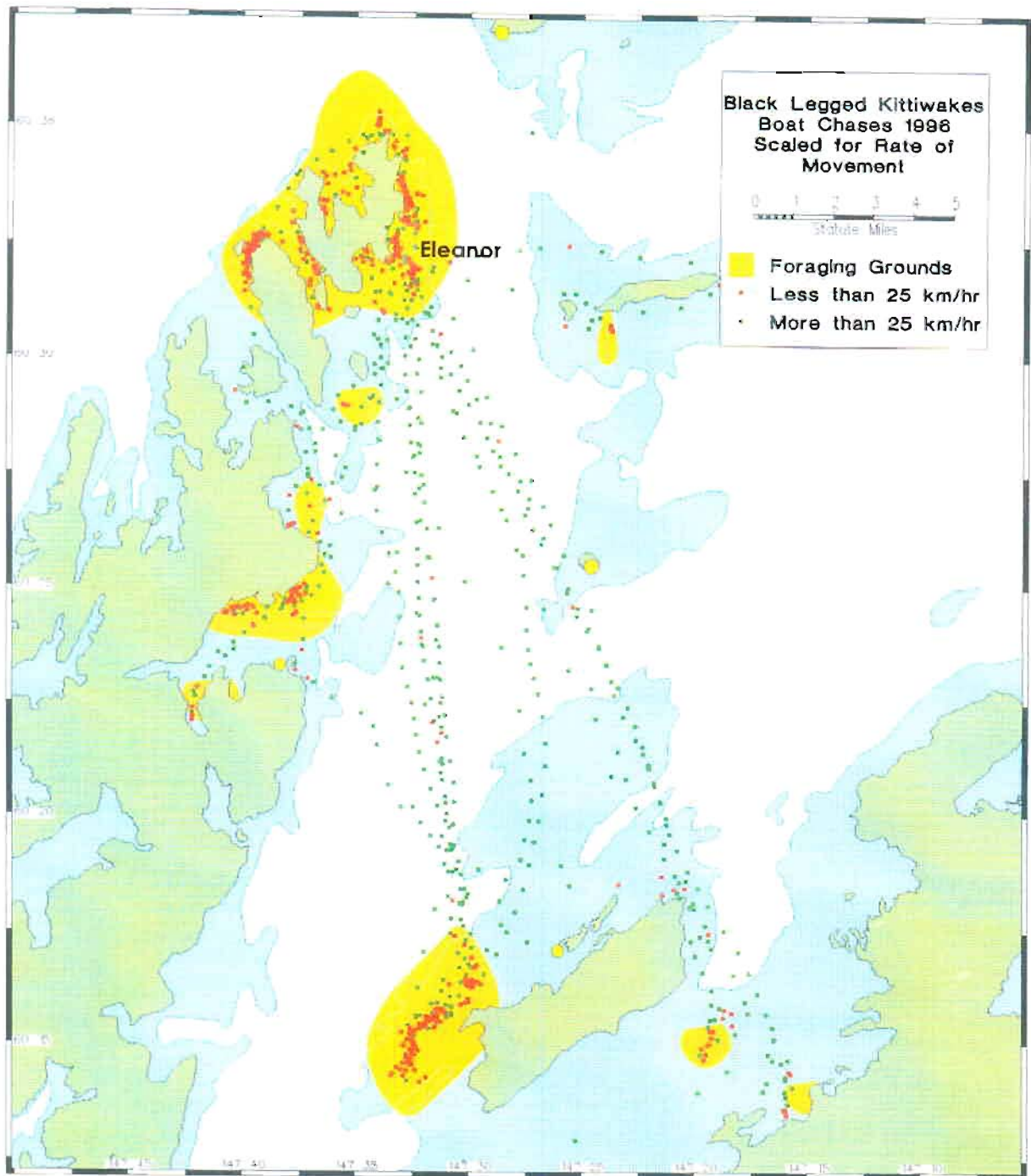
Figure 1. Results from boat chases of Black-legged Kittiwakes radio-tagged at the Eleanor Island colony, central Prince William Sound, 1996. Colony locations shown by yellow dots.
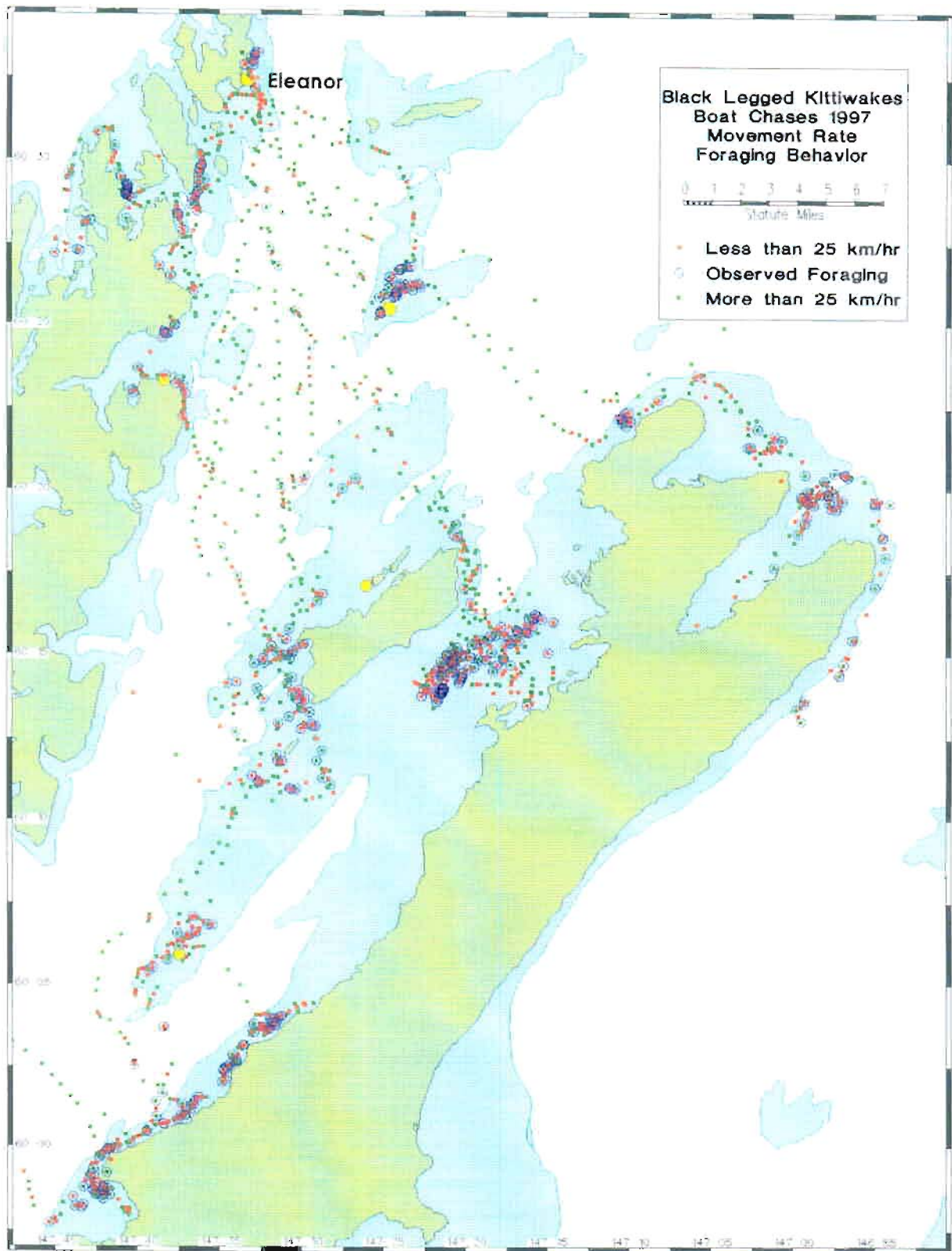
Figure 2. Results from boat chases of Black-legged Kittiwakes radio-tagged at the Eleanor Island colony, central Prince William Sound, 1997: rate of movement data compared to actual observations of foraging behavior. Colony locations shown by yellow dots.
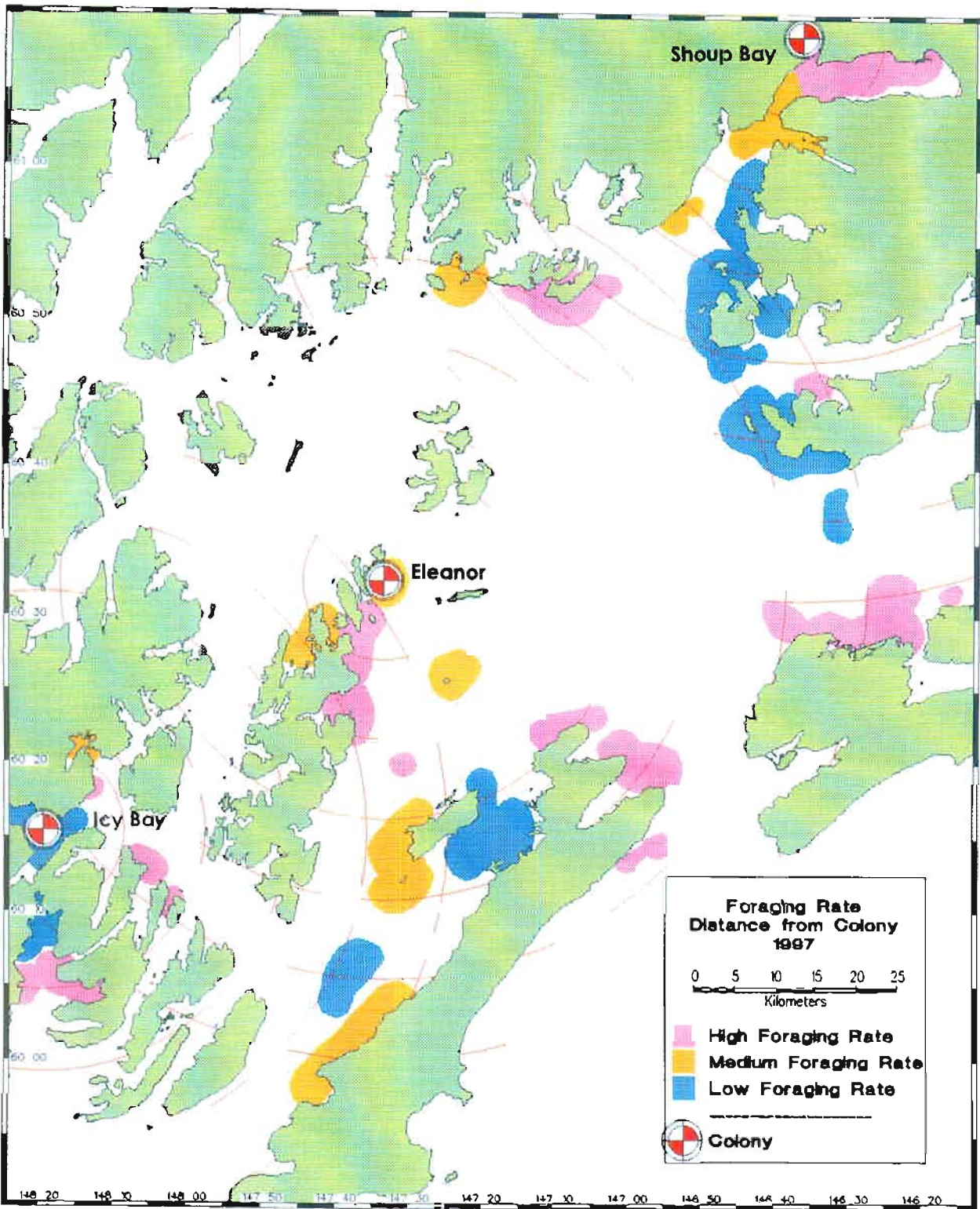
Figure 3. Foraging grounds in Prince William Sound scaled by feeding rate for each of the three kittiwake study colonies relative to distance from the colony; Prince William Sound, 1996: red is Shoup Bay, blue is Eleanor Island, and yellow is Icy Bay. The brightest color shows 95% of foraging, medium color intensity shows 90% of foraging, and dimmest color shows 85% of foraging. Colony locations shown by red-and-white symbols.

Shoup Bay ●

Eleanor ●

Icy Bay ●

Fish Biomass and
Fish Schools
1996

0   5   10   15   20   25
Kilometers

- .7491-32.36
- 32.36-74.91
- 74.91-168.6
- 168.6-298.7
- 298.7-362.6
- 362.6-543.9
- 543.9-725.2
- 725.2-1348.
- 1348.-2809.
- 2809.-4351.
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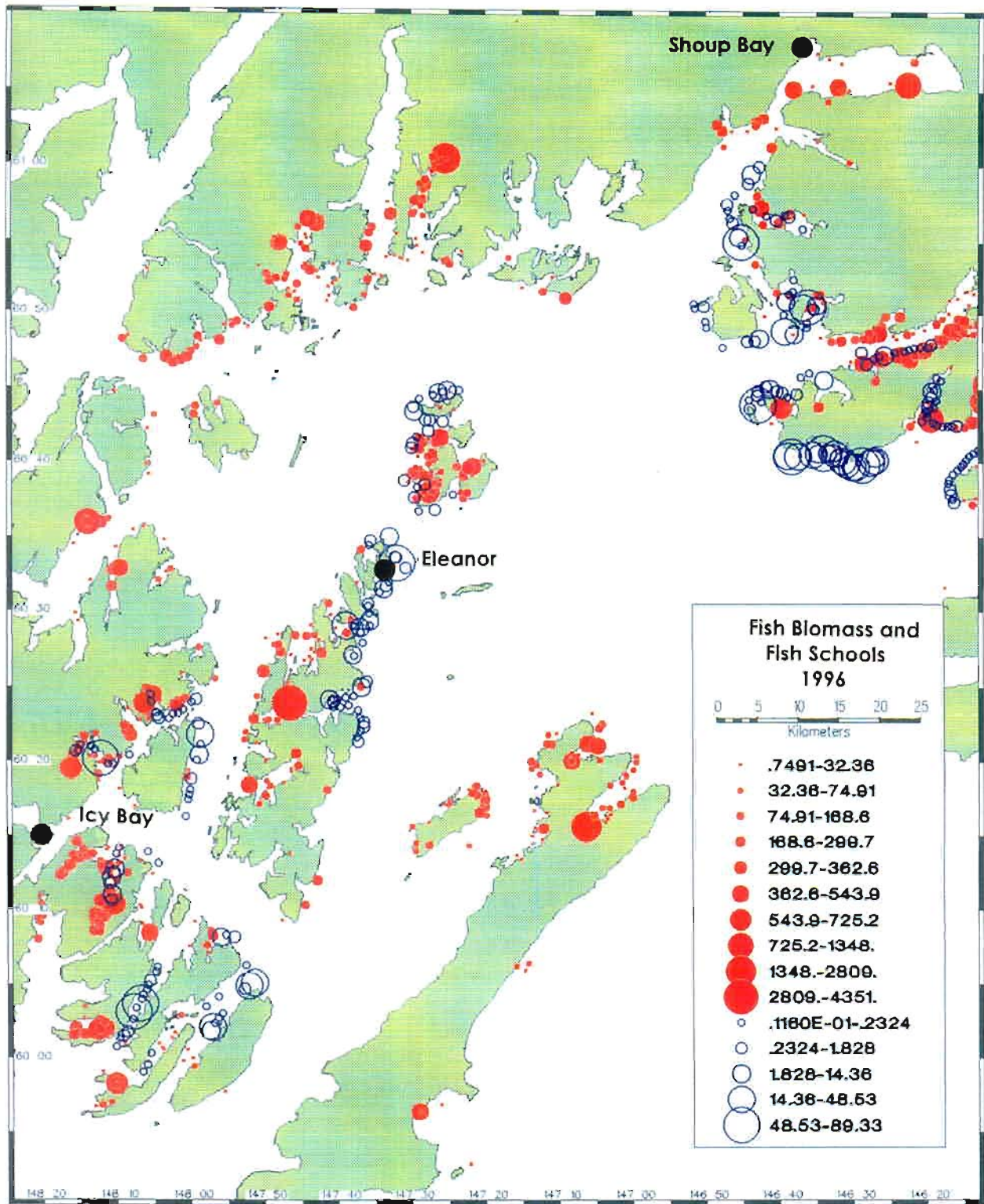- .2324-1.828
- 1.828-14.36
- 14.36-48.53
- 48.53-89.33

Figure 4. A plot of fish biomass (determined by hydroacoustics, blue circles) and the location of fish schools as determined from aerial surveys (red dots); Prince William Sound, 1996. Colony locations shown by black dots.
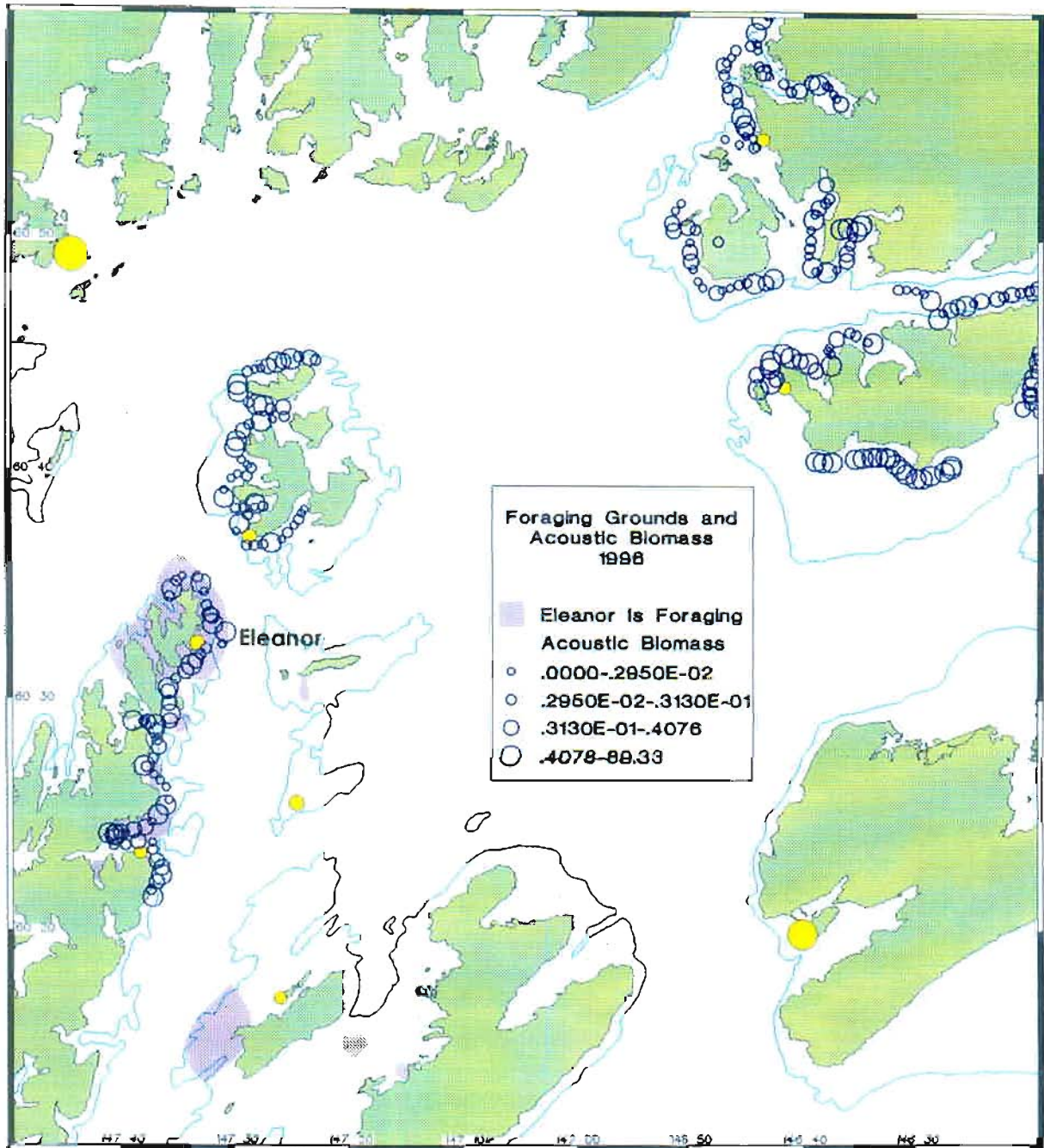
Figure 5. A plot of foraging grounds of kittiwakes from the Eleanor Island colony and fish biomass (determined by hydroacoustics); Prince William Sound, 1996. Colony locations shown by yellow dots.
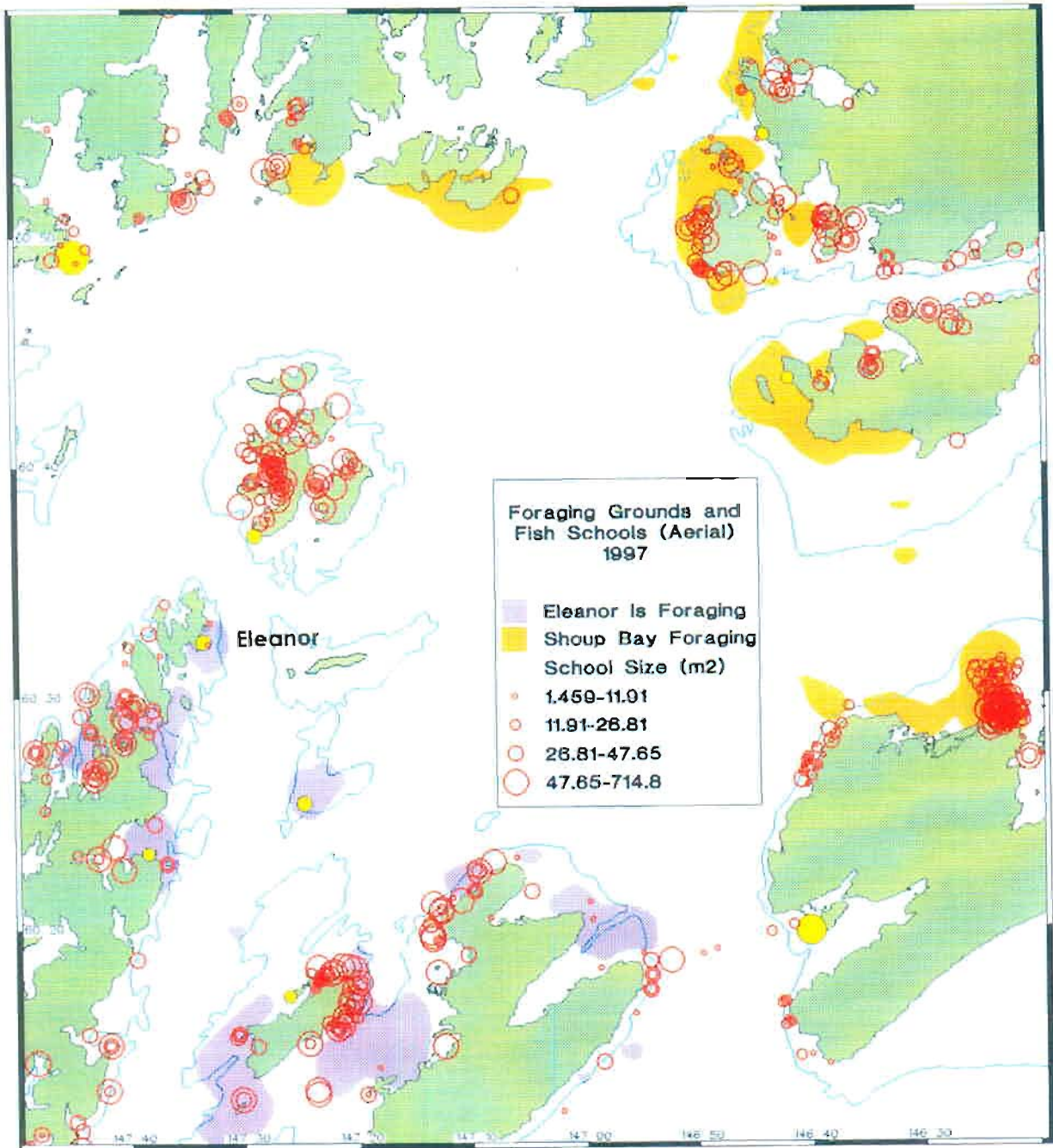
Figure 6. A plot of foraging grounds of kittiwakes from the Shoup Bay and Eleanor Island colonies and the location of fish schools as determined from aerial surveys; Prince William Sound, 1997. Colony locations shown by yellow dots.