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Marine Bird Biomass and Food Consumption in the South-Eastern Bering Sea
and some Southern Ocean Waters A Preliminary Comparison

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1. I n t r o d u c t i o n

In recent years there has been a growing interest in the role of seabirds as consumers in marine ecosystems. Two approaches have been used for estimating the trophic demand of birds, those based on the energy consumption at a colony (Furness 1978, Wiens et al. 1979, Croxall and Prince 1981, Furness and Cooper: 1982) and those based on the "energy requirements" of the biomass of birds using some oceanic region (Sanger 1972, Idyll 1973, Wiens and Scott 1975, Everson 1977, Mougin and Prevost 1980, Hunt et al. 1981, Jouventin and Mougin 1981, ~~Schneider and~~ Hunt 1982, Schneider et al. MS). Although most - **authors have used** the allometric equations of Kendeigh (1970) or Lasiewski and Dawson (1967) to convert avian biomass to energy required, others have used a fixed percentage of body weight as a crude estimate of needs (Hunt et al. 1981) or weight loss during starvation [(Jouventin and Mougin 1981), see Schneider and Hunt (1982) for a comparison **of** methods].

It is of *interest* to compare estimated carbon flux to birds in pelagic and near shore (colony) situations. Within the northern hemisphere, attempts at modeling carbon budgets in offshore marine ecosystems have assumed that birds play a distinctly minor role in marine carbon cycles (Andersen and Ursin 1977, Laevastu and Favorite 1981, Walsh et al. 1981). In contrast, colony-based studies provide evidence that consumption by breeding birds in the vicinity of colonies may be considerable (Furness 1978, Wiens et al. 1979, Furness and Cooper 1982), and may be influenced by competition with man (Furness 1983).

These comparisons of carbon flux to birds between pelagic and near shore areas gain added interest when made between the northern and southern hemisphere. The taxa and size classes of seabirds found in the two hemisphere vary greatly. When compared with estimates of local productivity, comparisons between the

hemispheres provide a means of identifying differences in the trophic roles of birds, and a clearer understanding of the ability of birds to exploit marine ecosystems. Unfortunately, the data required for such comparisons are widely scattered and in many cases missing. The present paper is a beginning for such comparisons based on recently completed pelagic counts of birds in the Bering Sea and in the Southern Ocean at comparable latitudes and Seasons.

2. Methods -

If useful comparisons are to be made between the northern and southern hemispheres, data from similar latitudes and seasons should be used since there are marked differences in seasonal and latitudinal distributions of birds (Shuntov 1972). To this end, the bird densities within 60 km of four colonies (islands) in the Bering Sea, St. Lawrence Island (63°N , 169° - 171°W), St. Matthew Island (60°N , 173°W) and the two main Pribilof Islands together (St. Paul 57°N , 170°W and St. George 55°N , 169°W), have been selected to compare with the density of birds within 60 km of the South Orkney Islands (Fig. 1), the only high latitude southern hemisphere colony for which there is presently comparable data. The distance of 60 km was chosen arbitrarily as the distance within which there was reasonably good coverage of bird distributions, although it is recognized that birds from colonies in both hemispheres fly further than 60 km in search of food (Croxall and Prince 1980, Hunt et al. 1982). Data from similar seasons are presented (Bering Sea - August, September, Southern Ocean - February, March), although a broader range of seasonal coverage is also presented for the Bering Sea.

Pelagic distributions of birds for the four domains of the southeastern Bering Sea shelf in Bristol Bay in August - September have been selected

to compare with distributions of birds documented in early March 1983 over the southeast Argentine continental shelf (Fig. 1). Four distinct oceanographic domains have recently been identified in the Bering Sea (Kinder and Schumacher 1981) and carbon flux to birds in these domains reflects interdomain differences in carbon flow (Iverson et al. 1979, Schneider and Hunt 1982, Schneider et al. MS) Data are unavailable to make similar oceanographic distinctions on the Argentine shelf. Data from a 9 March 1983 **survey in the** southern hemisphere are compared with those from a cruise from **16 August - 5** September 1980 in the Bering Sea.

Bird densities were measured by counting birds within a 90° sector from abeam of the ship to directly ahead and extending out 300 m to the side with the best visibility while proceeding at a known speed. Bird numbers were then divided by the area surveyed in each 10 minute period of observation to obtain densities (Hunt et al. 1982). Ship following birds were excluded from density calculations and no attempt was made to correct for ship-attracted birds (Schneider and Hunt 1982) because independent assessment of densities away from the ship using a helicopter was not possible in the southern hemisphere.

Energetic requirements of birds were estimated by calculating standard metabolic rate (SMR), based on the equation for nonpasserine birds (Lasiewski and Dawson 1967):

$$\text{SMR} = 78.3 \text{ M}^{0.723}$$

where $\text{SMR} = \text{kcal} \cdot \text{day}^{-1}$ and $\text{M} = \text{kg}$. Bird masses in the Bering Sea were obtained from birds collected in the study area and for species in the southern hemisphere, from Jouventin and Mougins (1981). Food required by active birds was estimated by multiplying SMR by the kcals needed per kcal SMR (existence energy, 2.5 SMR, MacMillen and Carpenter 1977, Weathers and Nagy 1980, Schneider and Hunt 1982,

an assimilation ratio of 1.4 (Kendeigh et al. 1977), 5 kcal·g⁻¹ dry weight for fish (Nishiyama 1977) and 0.27 g dry weight ·g wet weight⁻¹ for fish (Cooper 1979). A conversion of 0.4 g C·g dry weight⁻¹ fish, squid and arthropods (Curl 1962) was used.

3. Results

3.1 Shelf waters away from colonies

The carbon demand of seabirds in Bristol Bay, Bering Sea was 1.59X that found over the Argentine shelf for a comparable time of year, a difference less than that found between domains in the Bering Sea (Table 1). Although a lack of oceanographic data precluded assigning the Argentine shelf observations to domains -comparable to those of the Bering Sea shelf, the cruise track crosses from deep water into the center of the shelf (Fig. 1). The similarity in carbon demand between hemispheres is striking given the 2.4 fold higher density of birds in Bristol Bay. However, the biomass of birds per unit area in Bristol Bay was only 1.25 that in Argentine waters due to the smaller average size of birds encountered in the north. This smaller average size contributed to the proportionately greater carbon demand in the north due to the allometric nature of the metabolic equations.

The rate of carbon flux to surface vs subsurface feeding birds was also remarkably similar in Bristol Bay and the Argentine shelf (Table 1). Analysis of carbon flux pathways in different domains of the Bering Sea shelf show striking changes between domains, with most carbon going to surface foragers in the shelf-edge domain and to subsurface foragers in the inner domain (Table 1). In the shelf-edge and outer domains Northern Fulmars (Fulmarus glacialis) were the predominant consumers, while in the middle and inner domains Short-tailed Shearwaters (Puffinus tenuirostris) that took euphausiids (Thysanoessa sp.) were dominant.

3.2 Waters near colonies

St. Lawrence Island supports colonies in the Bering Sea at a latitude comparative - to the South Orkneys in the Southern Ocean, but there was an inadequate sample - for August -- -September, the period most comparable to February - March in the south. . Samples from throughout the breeding season at St. Lawrence "were" therefore compared with those from near the end of the season at South Orkney.

The biomass of birds per. km² within 60 km. of St. Lawrence Island was 1.11X that near the South Orkneys, a remarkable similarity given the relatively meager sampling effort available for the two island-s (Table 2). However, energy consumption by birds near S c. Lawrence Island was 1.74X that near the South Orkneys due to the smaller size of the birds near St. Lawrence (mean mass, 305 vs 1581 g·bird⁻¹).

Near the South Orkneys, major differences in avian density, biomass km⁻² and carbon flux to birds were found between waters less than and greater than 1000 m in depth. Density over the deeper waters was half that over shelf waters (24.5 birds·km⁻², N=169 counts vs 50.9 birds·km⁻², N=69 counts). Biomass was three times greater on the shelf (9.0 x 10⁴ vs 2.9 x 10⁴ g·km⁻²) as was carbon flux (15.4 x 10⁴ Vs 4.7 x 10⁴ g C·m⁻²·day⁻¹). Birds over the shelf were of greater mass on average (1767 vs 1166 g·bird⁻¹) and the most important contributors of biomass were Pygoscelis Antarctica, F. glacialis and Diomedea melanophris. These same three species were also the most important over deeper water, but in addition there was a dramatic increase in Pachytila desolata (3.1 to 8.7 birds·km⁻²).

For waters near all colonies examined, the major biomass of birds was concentrated in subsurface foragers (Table 3). In the Bering Sea these were represented by murre (Uris sp.) and small auklets (primarily Aethia sp.) .

Near the South Orkney Islands Chinstrap Penguins (P. Antarctica) dominated. At South Georgia Island, where surface foraging birds predominate on the colonies, avian foraging biomass close to the island is mostly subsurface feeding penguins (Croxall, pers. comm.).

At the South Orkneys a substantial portion of the avian biomass was represented by Black-browed Albatross (D. melanophris), whose closest large breeding colony is on South Georgia Island. In contrast, at St. Lawrence and St. Matthew Islands in the Bering Sea, relatively little of the nearby avian biomass was represented by birds other than those associated with these colonies. However, near the Pribilof Islands and to the south in Bristol Bay, migrant shearwaters (Puff inus sp.) from the southern hemisphere made a significant contribution to avian biomass.

The values of biomass and carbon flux to birds near colonies in either region must be treated with great caution. Comparison of data from the Pribilof Islands from the entire season with those from the end of the season show a twofold decrease in carbon demand (Table 2). This drop reflects the departure of murre and Least Auklets (Aethia pusilla) during the latter part of August (Hunt et al. 1982). Similar seasonal changes may influence bird counts around St. Lawrence Island.

The biomass of birds supported by the nearshore waters of the south Orkneys may have been underestimated for two reasons (Trivelpiece, pers. comm.). Adelle Penguin populations there are large, but the birds had departed formoulting grounds on the Weddell Sea ice pack prior to our visit. Thus, due to the time of our census, approximately one half of the penguin biomass was absent. Additionally, we may have underestimated Chinstrap Penguin populations. Failed breeders and pre-breeding younger birds are ashore moulting in mid-February to mid-March and successful breeders may concentrate foraging closer to the island

than we were able to survey adequately. It is hard to estimate the effect of these sampling problems on the comparison between hemispheres, especially since similar arguments in modified form may apply to the waters near the Bering Sea colonies.

Additionally, for large islands where colonies are restricted to a limited area, such as at St. Lawrence and SC. Matthew Islands, the distribution of survey effort can greatly affect density estimates. Cruise tracks were not identical on the two St. Matthew cruises and this may partly explain the 1.7 difference in carbon demand. Local patchiness in bird distribution may also contribute to variance if sampling effort is small ($< 50 \text{ km}^2$ sampled).

4. Discussion

This paper represents a preliminary attempt to compare seabird densities, biomass, and carbon demand between areas of roughly equivalent latitudes and at roughly equivalent seasons in the northern and southern hemispheres. Densities were generally lower in the southern hemisphere for similar situations (close to colony, removed from colony), but because southern hemisphere birds were on the average larger, biomass per unit area was remarkably similar between the two hemispheres. Carbon flux to birds was, if anything, lower in the southern hemisphere due to allometric considerations. This result suggests that, in relation to their ability to support marine birds, the waters studied in the Scotia Sea and in Bristol Bay of the Bering Sea were roughly equivalent. There was certainly no support for a higher productivity with respect to birds in the Southern Ocean over shelf waters away from colonies (Bristol Bay vs Argentine Shelf) where sampling problems were less severe than near colonies.

The notion that bird life may be more abundant in the Southern Ocean may result from the immense numbers of birds found breeding on the larger sub-Antarctic islands such as South Georgia. Seabirds on South Georgia require 4.6×10^6 metric tons of food each breeding season (Croxall et al. in press), compared to 5.4×10^5 metric tons per breeding season on the Pribilofs (Wiens et al. 1979). While at present we lack sufficient data to characterize the area of ocean required to support the bird populations on South Georgia, albatrosses breeding there forage over vast areas of ocean, frequently 900-2650 km from their colonies based on the calculations of Croxall and Prince (1980) and observations (Hum and Veit, pers. obs.) of marked birds from South Georgia in the vicinity of the South Orkneys. In contrast, bird densities at sea are sufficient to account for all foraging by Pribilof Island birds within 110 km of the islands, although it is reasonable to assume fulmars and kittiwakes (*Rissa* sp.) fly greater distances in search of food. The southern hemisphere colonies may be larger because the procellariiformes that nest there are adapted to search for food over greater distances than is true for most northern hemisphere species. This ability is made possible not only by their lower wing loading (Ainley et al. 1974, Croxall and Prince 1980, Jouventin and Mougin 1981) but also by the adaptation of their chicks to survive periods of fasting while parents search for food (Croxall and Prince 1980).

It is also interesting to compare pathways of carbon flux to birds in different ocean regions or domains. Schneider and Hunt (1982) found significant differences in the extent of carbon flux to surface and subsurface feeding birds in the domains of the shelf waters of the Bering Sea. These results have been confirmed and extended by recent work (Schneider et al. MS). The results presented here, based on a single cruise chosen because of its

seasonal correspondence with the survey over the Argentine shelf reflects, in part, the pattern observed in the more comprehensive studies. The similarities in bird biomass and in the ratio of surface to subsurface carbon flux to birds suggest that processes similar to those found in the Bering Sea shelf may be found in the waters off Argentina.

The predominance of subsurface foragers in waters near colonies is undoubtedly the result of a combination of factors (Croxall and Prince 1980). In the north, wing loading of alcids is greater than that of the surface foraging procellariiformes and gulls and thus the greater cost of flying would restrict alcid use of distant foraging grounds (Cody 1973). Similar energetic arguments would apply to penguins in the southern hemisphere. Additionally, subsurface foragers can pursue prey through a large portion of the inshore water column, while surface foragers are restricted to catching prey when they are near the surface. One might expect that surface foragers would be at a competitive disadvantage to subsurface foragers when foraging in inshore waters.

Our data sets for regions other than Bristol Bay and the Pribilof Islands are small and the numbers presented here must be considered provisional. However, the prospect of making quantitative comparisons between bird faunas of the northern and southern hemispheres is exciting. These comparisons provide a new tool for examining the bird communities of the two regions and their adaptations. The comparisons may also lead to new insights about the dynamics of marine ecosystem in the two regions.

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Table 1. Trophic demand of seabirds distant from coasts.

LOCATION	Birds $\cdot \text{km}^{-2}$	g Bird $\cdot \text{km}^{-2}$ $\times 10^4$	Ave. Mass (\bar{x})	Carbon demand g $\text{C} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ $\times 10^{-4}$	ratio surface: subsurface carbon flux
Argentine shelf ¹	23.4	2.70	1152	7.1	0.30
Bristol Bay ²	55.2	3.37	610	11.31	0.28
Slope	19.6	1.16	591	2.66	1.60
Outer	57.9	3.60	621	9.09	0.23
Middle	59.0	3.80	645	9.61	0.2
Inner	77.0	4.95	642	12.42	0.09

¹March 1983, 57 counts, see figure 1 for area surveyed

²Cruise 580; 16 Aug - 5 Sept 1980, slope - 25 counts, outer - 26 counts, middle - 30 counts,
inner - 18 counts

Table 2. Trophic demands of seabirds within 60 km of colonies based on counts made during shipboard surveys

COLONY	No. 10 minute counts	bl. g. km ⁻²	g. bl. km ⁻²	AV. g. km ⁻²	CO. km ⁻²
A. SEASON North August - September, South: February - March					
<u>Bering Sea</u>					
Pribilof Is.	746	72.3	54.68	7.97	17.2 x 10 ⁻⁴
St. Matthew Is.	25	186.3	116.04	52.3	17.2 x 10 ⁻⁴
St. Lawrence Is.	17*				
<u>Scotia Sea</u>					
South Orkney Is.	92	62.3	93.92	158	22.1 x 10 ⁻⁴
B. SEASON May - October					
Pribilof Is.	1360	129.2	122.1	8	32.1 x 10 ⁻⁴
St. Matthew Is.	140	93.3	71.40	27.3	22.1 x 10 ⁻⁴
St. Lawrence Is.	107	360.2	109.34	205	40.1 x 10 ⁻⁴

*Sample too small to trust

Table 3. Species contributing major portion of biomass ($10^3 \text{ g} \cdot \text{km}^{-2}$) near colonies.

	PRIBILOFS		PRIBILOFS		ST. MATTHEW		ST, MATTHEW		ST, LAWRENCE	
	May-Oct		Aug-Sept		May-Ott		Aug-Sept		May-Oct	
	biomass	%	biomass	%	biomass	%	biomass	%	biomass	%
<u>Fulmarus glacialis</u>	3.28	3	2.39	4	3.19	4	0.56	<1	0.88	1
<u>Puffinus</u> sp.	3.68	4	6.36	12	0.39	1	0.91	1	0.00	0
<u>Rissa</u> sp.	3.29	3	2.95	5	0.97	1	1.07	1	3.93	4
<u>Uria</u> sp.	91.34	87	40.40	74	63.03	88	98.21	85	99.86	51
<u>Aethia pusilla</u>	0.55	1	0.03	<1	0.80	1	4.05	3	13.71	12
other small auklets	0.63	1	0.32	1	2.08	3	7.61	7	33.73	31
<u>Fratercula corniculata</u>	0.37	<1	0.45	1	1.00	1	2.64	2	0.34	<1

SOUTH ORKNING ISLANDS

	biomass	%
<u>Pygoscelis antarctica</u>	60.42	61
<u>Diomedea melanophris</u>	8.96	9
<u>Diomedea chrysostoma</u>	2.55	3
<u>Macronectes giganteus</u>	1.74	2
<u>Fulmarus glacialisoides</u>	21.08	21
<u>Daption capensis</u>	1.31	1
<u>Pachyptila desolata</u>	1.27	1

Figure Legend

Figure 1. Cruise tracks on the Argentine shelf and near the South Orkney Islands. Observations were made on a continuous basis along the lines indicated.