Proceedings of the Sardine Symposium 2000

May 23-25, 2000

Held at the

Scripps Institution of Oceanography and
the National Marine Fisheries Service's
Southwest Fisheries Science Center
La Jolla, California

Symposium Sponsors

The coordinators of the Sardine Symposium 2000 expresses its gratitude to the both the National Marine Fisheries Service and Scripps Institution of Oceanography for use of their facilities during the symposium. We also wish to thank the following sponsoring government agencies and private organizations for their financial support that made the symposium possible.

California Seafood Council
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Proceedings of the Sardine Symposium 2000

Stephen H. Phillips, Editor

Published by

Pacific States Marine Fisheries Commission
45 SE 82nd Drive, Suite 100
Gladstone, Oregon 97027-2522
Tel: (503) 650-5400 Fax: (503) 650-5426

October, 2000

Funding support for the publication was provided by the
Southwest Region of the National Marine Fisheries Service,
Long Beach, California

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Of Sardines and Seabirds

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Although seabirds are often overlooked by scientists, fishers, and fishery managers as significant marine predators, in fact, many species feed exclusively on finfish, including the juveniles of many important commercial species (e.g., rockfish, salmon), as well as on the adults of commercially important baitfish (e.g., anchovy, herring). The degree to which seabirds impact fishery stocks thus depends on the abundance of each piscivorous seabird species and their diet (also expressible more generally as daily energetic demand). Because many piscivorous seabirds take forage fish, the re-emergence of sardines (*Sardinops sagax*) over anchovies within the California Current System (CCS) may create both trickle down and trickle up change in nearshore systems.

Seabirds are marine birds foraging primarily to exclusively in the marine environment. Many species spend the majority of their lives on the ocean, returning to land only to breed. Seabirds are generally long-lived (20-70 years, depending on the species), and display many life history traits common to mammals: sexual maturity is delayed several years, annual reproductive output is low (from a maximum of 3 chicks in the gulls and terns, to a minimum of one chick every other year in some albatross), juvenile survivorship is low, and adult survivorship is usually high (90+ percent annually). Because of the tradeoff between long life and low fecundity, seabird populations are vulnerable to decline if adult survivorship decreases by as little as 3-5%. Many seabirds are natally philopatric – returning to their place of birth to breed. This latter trait has the potential to create somewhat closed populations, if environmental conditions remain favorable at the colony site.

Within the CCS, seabirds are found both breeding and as non-breeders. This latter category includes young individuals (prebreeders), individuals which have elected to skip breeding in any given year, and species which breed elsewhere, but spend time foraging in the CCS (Table 1). In total, 16 primarily piscivorous seabird species (excluding minor gull species) are found within the nearshore CCS (defined herein as from the shoreline out to 2000 meters of depth). For this analysis, we divide the CCS into political regions (British Columbia, Washington, Oregon, and California), and further subdivide California into north and south (subdividing the State at Pt. Conception). Although oceanographic regions may be more biologically appropriate, data are most often reported by state.

There are several patterns of note. First, several species occur during the summer, but are not found in substantial numbers in the winter (e.g., pelicans, shearwaters, albatross), and vice versa. The latter two species breed outside of the CCS (southern hemisphere and Hawaii, respectively). Kittiwakes and fulmars (the Alaska breeders) are only found in the CCS during the winter.

Second, some species exhibit a cline in distribution (e.g., pelicans are found in the south, but not in the north; murres are found predominantly in the middle of the CCS). Third, some species appear to have an erratic distribution and abundance pattern (e.g., rhinoceros auklets). This latter pattern may be more indicative of data quality, than biological reality, and reflects the fact that the smaller, burrow nesters are harder to adequately sample both during the breeding season and on the water in the winter.

Abundance, although useful, does not adequately represent seabird pressure on forage fish resources, because piscivorous seabirds range widely in mass from black-legged kittiwakres (.04 kg) to black-footed albatross and brown pelicans (3.0 kg). Figure 1A shows annualized biomass (metric tons) for all species combined. Using standard field and laboratory-derived measurements, as well as occasional allometric standardization equations, it is possible to calculate a second parameter – energy demand (billions of Kcal; Figure 1B). In total in the CCS, we estimate 3606 metric tons of seabirds annually demand 431 billion kilocalories of fish. Note that these estimates only include adult birds, and do not include the chicks produced within the breeding season. Thus, these values are conservative. Because the nearshore environment differs greatly in size among the political regions of the CCS, we have also divided seabird biomass and energy demand by region size, to produce annual estimates per kilometer squared (Figure 2A & B).

Energy demand can be translated into biomass of forage fish using literature-derived values for forage fish energy content (in kcal/g). Thus, if seabird diet is known, total biomass for each fish species consumed can be calculated. Results of such a calculation are shown for common murres (*Uria aalge*), by region, based on gut contents from birds collected at sea and observation of fish brought back to chicks (Figure 3). Of course, during the breeding season, murres and other CCS breeders do not range evenly over the nearshore, but are found clustered adjacent to the colony. Assuming murres have a foraging range of 30 km, prey consumption for the largest colonies may be 5-15 times higher than the estimates given in Figure 3.

Will sardines be affected by seabird energy demands? We conservatively estimate total seabird biomass in the nearshore CCS at 3,600 metric tons. Excluding chicks, these birds require 431 billion kilocalories each year. Thus, depending on which prey species are consumed, seabirds eat 220-300 thousand metric tons of fish annually. Because sardines are a high energy content fish (2.08 kcal/g), second only to eulachon (*Thaleichthys pacificus*) and well above anchovy (*Engraulis mordax*; .094 kcal/g), they should be a preferred food resource for any predator. If all seabird demand was satisfied by sardines, seabirds would consume 0.21MMT, or approximately 13% of the 1999 total age1+ population estimate (1.58MMT). This is approximately twice as much as the fishery landed in 1999.

However, there are several reality caveats. First, sardines should be highly desirable as food, especially as food for chicks because adults must transfer fish back to the colony. Thus, low value fish such as Pacific cod (Gadus macrocephalus, 0.94 kcal/g) would require many more trips to satisfy the energy demands of the chick(s). Second, because sardines have a higher energy value than anchovies, there may be additional predation pressure on sardines. At the same time, the ecosystem may produce a lower biomass of sardines, if trophic energy is conserved. In other words, a kilogram of anchovies is worth only 0.76 kg of sardines, if the currency is energy rather than biomass. Third, adult sardines are large enough to escape seabird predation, potentially falling prey to only the largest species of gulls, cormorants, pelicans, and albatross. However, these seabird species make up a minor proportion of the total seabird biomass (15 %). Thus, seabird predation on sardines may actually be less than that on anchovies (per fish biomass) during the previous half of the cycle. In this case, the replacement of sardines by anchovies may negatively affect seabirds by effectively removing a food source. Finally, because all seabirds can take juvenile sardines, seabird predation may have the greatest effect on the early life history stages. Since the last cycle of sardine dominance, seabird populations throughout the CCS, particularly breeding seabirds which must target smaller fishes to feed their chicks, have grown substantially. Whether this route of trophic interaction significantly affects sardines, for instance by depressing the re-initiation of sardine predominance, is not known.

Table 1. Summer and winter population estimates for seabird taxa in the CCS, by region. Data are taken from a variety of published sources and represent an amalgam of at sea and on colony counts and estimates from the 1970s through the 1990s. Data quality vary greatly across regions.

	BC	WA	OR	nCA	sCA
Summer					
Murres	13000	15000	1068000	527000	0
Rhinos	1078500	91200	1500	2600	0
Gulls	86900	59900	25500	50700	41900
Cormorants	19900	9800	81500	81000	44000
Puffins	116900	4500	7500	0	0
Terns	0	0	24000	0	0
Pelicans	0	0	0	0	17900
Shearwaters	114000	415000	55700	2161700	107500
Albatross	14100	4400	3300	20100	600
Winter					
Murres	33700	94500	97800	296400	0
Gulls	31100	35900	22400	227700	838700
Rhinos	25500	1000	1400	149900	0
Kittiwakes	0	28000	12500	103800	42100
Fulmars	9400	68300	7600	23000	85500
Cormorants	7500	5700	5000	8400	0

Figure 1A & B. Annual total biomass and total energy demand by region for all species listed in Table 1 combined.

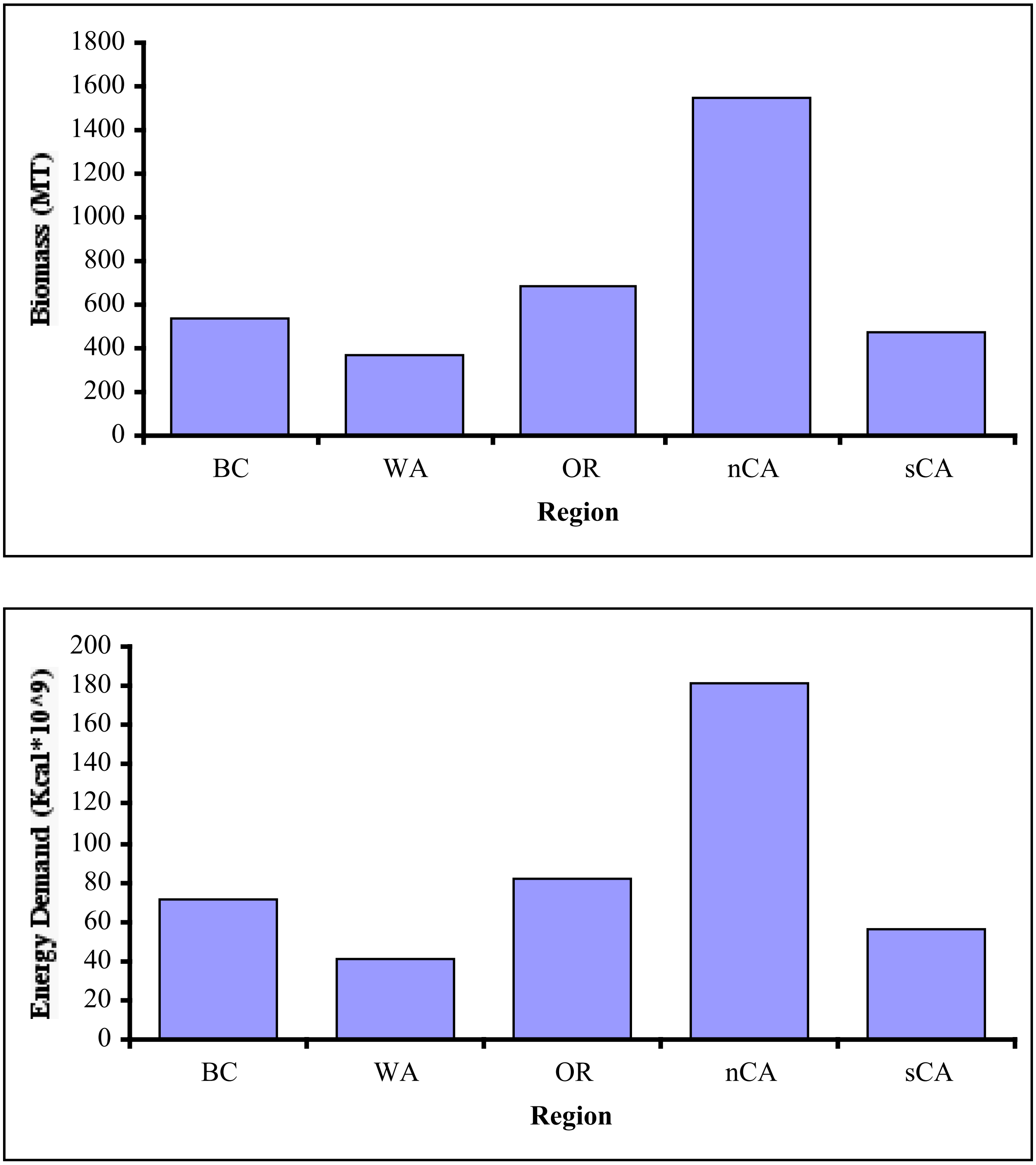

Figure 2A & B. Annual biomass and energy demand per km^2, by region.

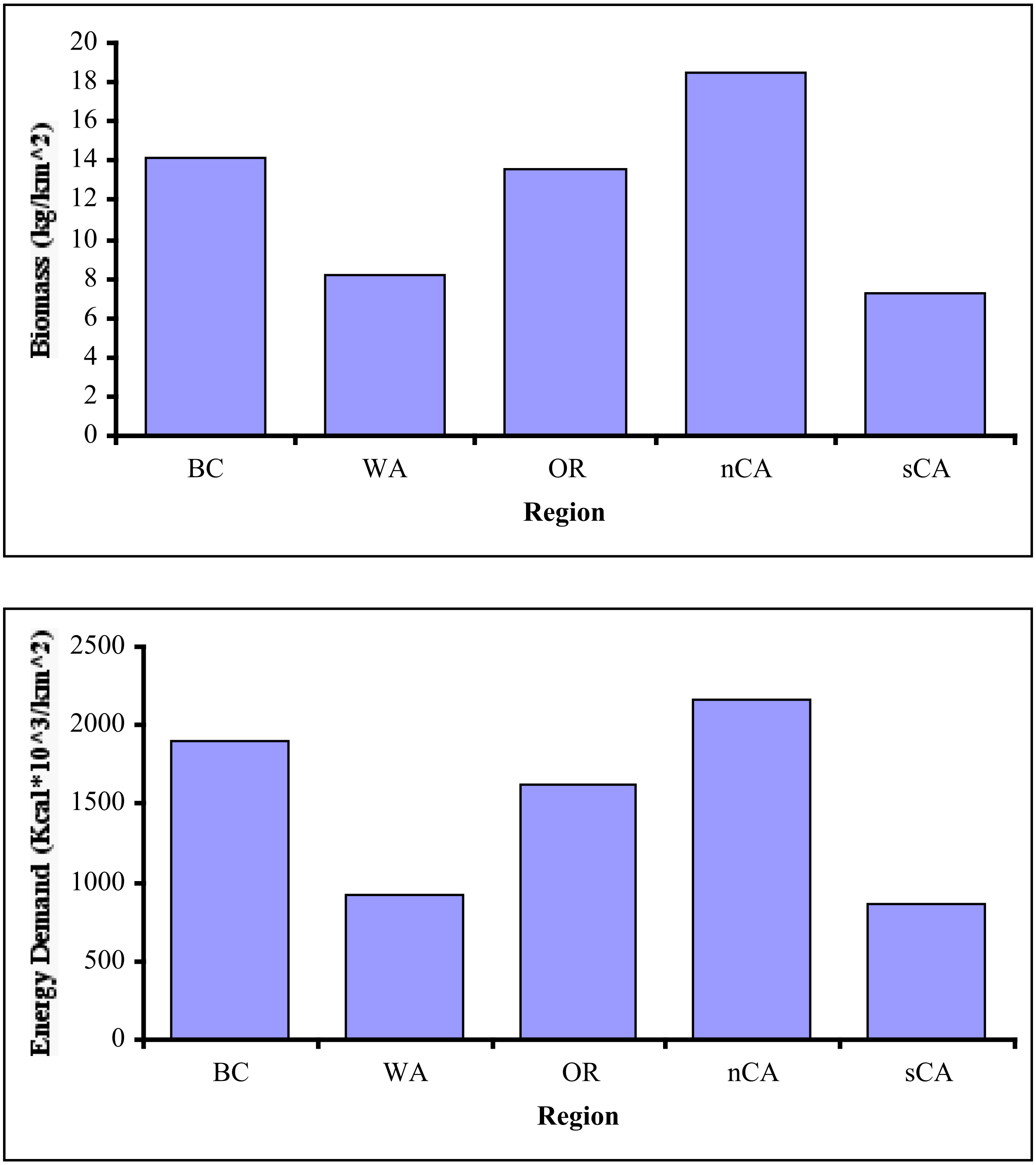

Figure 3. Annual prey consumption in MT of common murres, by region.