

OCCURRENCE PATTERNS OF SEABIRDS IN THE CALIFORNIA CURRENT GLOBEC STUDY AREA: INDICATORS OF TOP-DOWN INFLUENCES ON FOOD-WEB STRUCTURE

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SUMMARY

We investigated the occurrence patterns of seabirds in the GLOBEC-Northeast Pacific-California Current study area during a process cruise, 30 May to 13 June 2000. Using flux-adjusted strip transects, we estimated the density and biomass of seabirds by following a fixed grid that extended along shore from Newport OR to Crescent City CA and offshore from the beach to well beyond the continental shelf break. Characteristics of the water column were measured nearly simultaneously (0-24 hrs) using SeaSoar technology. During the cruise, intense upwelling alternated with a downwelling episode, and marked blooms of phytoplankton were evident. In a multi-regression model using variables currently available, a respectably high (for seabirds) 29% of variation in log biomass (all seabird species combined) was explained, essentially, by depth of the 10° C isotherm, depth of the chlorophyll maximum, and the chlorophyll maximum value itself. Among individual species, 57.5% and 31.4% of variation in log biomass was explained for Rhinoceros Auklet and Common Murre (two known predators of juvenile salmon, the GLOBEC target species) by the chlorophyll maximum and its depth, plus interactions with other variables. It was not possible (but may be so in the future) to include in this analysis variables related more directly to seabird prey. In fact, seabirds did not occur at the centers of phytoplankton blooms but rather at their edges. Seabirds are not vegetarians but feed on the organisms that graze phytoplankton (euphausiids) or that eat the grazers themselves (small fish). Therefore, the concentration of top-trophic predators (seabirds) foraging at the edges of high biomass phytoplankton blooms, including "holes" within the blooms, may indicate that the spatial extent of the blooms may be influenced (controlled) greatly by grazing.

BACKGROUND

Studies of the occurrence patterns of seabird species in the California Current, and elsewhere, have been constrained by an inability to simultaneously quantify the occurrence patterns of their prey. On the other hand, underway sampling of physical features, especially sea-surface temperature and salinity, have been possible; as have, in some cases using CTD casts, quantification of mixed-layer depth and thermocline/halocline intensity. Results indicate that many seabirds in this region are closely tied to upwelling and other frontal features (Briggs et al. 1986, 1987; Hoefler 2000, Oedekoven et al. 2001). In the interpretation of results the assumption or implication has been made that the physically-defined fronts are proxies for elevated prey concentrations or increased prey availability. Indeed the latter is a generally accepted truth in regard to the distribution of the euphausiids and small fish upon which seabirds feed (e.g., Ainley et al. 1993). On a larger scale, changes in seabird abundance in accord with physically-defined climate changes in the California Current System have also assumed that the link involves the seabird prey (Ainley et al. 1995, Veit et al. 1997).

The Northeast Pacific GLOBEC (California Current) project is investigating the link between ocean climate and occurrence patterns of certain mid-trophic level organisms (euphausiids, juvenile salmon), whose variation in abundance greatly affects food web structure. We have been investigating seabirds (and marine mammals) as predators and competitors of these GLOBEC target species. As a result, we enjoy the opportunity to relate seabird occurrence to a more complete suite of environmental variables, including both physical and biological features, than is usually possible. Herein we report analyses preliminary to the point where information on zooplankton and micronekton will be available.

METHODS

During the period 30 May to 13 June 2000 we estimated the density (and subsequently the biomass) of seabirds along the tracks that compose the GLOBEC NEP-CC study area, which extends from the shore to well beyond the shelf break from Newport OR to Crescent City CA (Figure 1). Seabirds that occurred within 300 m of one forequarter of the ship (90° bow to beam) were tallied. Behavior such as flight direction or feeding was noted; birds sitting on the water were assumed to be located where they had recently fed (and therefore included as "feeding"). Continuous counts were segmented into 15-min bins. Density was estimated: birds present divided by area of ocean surface surveyed (300 m X distance traveled in 15 min); estimates including flying birds (flux) were adjusted according to the relative speed and direction of the birds and ship (Spear et al. 1992). Herein, however, we include only feeding (on water or in non-directional flight) individuals.

On a separate ship, ocean climate was recorded using SeaSoar technology, which provided ocean sections of temperature, salinity, fluorescence and other factors. Acoustic data were also gathered but are not yet available to relate patterns to seabird occurrence. Both ships operated in tandem as well as possible, and sampled the same track within 0-24 h of one another both in a mesoscale and two fine-scale grids (subset of mesoscale). The SeaSoar data were averaged for each 1 m depth for bins that matched the seabird census 15-min segments. A comparison of surface temperature and salinity logged on the survey ship was closely correlated to that available from the SeaSoar ($r^2 = 0.92$). Therefore, we assumed other SeaSoar variables were consistent as well, i.e. had not changed appreciably within any time lag that existed between ships as to when they passed along the track.

We used multiple regression (Stata Corp 1999) to deduce the factors that best explained variation in seabird occurrence. Biomass was log transformed as the dependent variable.

RESULTS

Important variables were those that indicated frontal features driven by upwelling, such as depth of the 10° C isotherm, thermocline and halocline (mixed layer) depth, and thermocline and halocline slope (intensity of the clines, e.g. change in temperature in the first 20 m of the thermocline) (Tables 1-3). However, by far the most important variables explaining seabird occurrence were the depth of the chlorophyll maximum and the maximum value itself. For all seabird species combined (feeding individuals), the regression model explained 28.7% of variation in bird occurrence. Only in very large-scale investigations (i.e., entire California Current system) is the explanatory power greater (e.g., Hoefler 2000).

Variation in occurrence for some species was explained little by our analysis (e.g., Leach's and Fork-tailed Storm-Petrel, <10%). For Black-footed Albatross the model explained 20.1% of occurrence variation, and for Common Murre and Rhinoceros Auklet, two known predators of juvenile salmon, 31.4 and 57.5%, respectively, of their occurrence was explainable by the suite of factors available to us for analysis (Figures 1, 2). Interesting was the fact that these birds were largely absent where there was little if any bloom. They occurred in the vicinity of blooms but not at the chlorophyll maxima. Rather, they concentrated along the edges of blooms (Figures 1-4). Common Murres, which can dive to >100 m deep occurred mainly inshore of the blooms. Rhinoceros Auklets, on the other hand, which can dive deep but perhaps not to 100 m, occurred offshore of the blooms.

In spite of a switch from upwelling to downwelling during the course of the cruise, blooms remained in place. Accordingly, the seabird patterns did not alter greatly between the two periods (Figures 3, 4).

Table 1. Multiple regression model for the relationship between log seabird biomass (feeding individuals only, all species) and oceanographic variables, including sea-surface temperature and salinity, depth of 10°C, depth thermocline depth and slope (intensity), halocline depth and slope, chlorophyll maximum value, and depth of chlorophyll maximum. Values are shown in order of decreasing significance. Rejected terms were re-entered into the model as main effects when testing for interactions involving respective terms. Two terms separated by an "x" denotes an interaction between respective terms. Sample size was 317 fifteen-minute survey transects. All numerator of = 1.

Model F[14, 302] = 8.68, P < 0.0001, 28.7% variation explained.

Main effects:	Sign	F	P
Chlorophyll depth @ max	(-)	39.35	<0.0001
Chlorophyll depth @ max ²	(+)	9.45	<0.01
Chlorophyll maximum	(+)	27.82	<0.0001
Depth of 10°C	(-)	19.31	<0.0001
Depth of 10°C ²	(-)	4.69	<0.05
Sea-surface salinity	(+)	6.30	<0.05
Halocline slope	(-)	1.38	0.2
Halocline slope ²	(+)	5.22	<0.05
Interactions:			
Sea-surface salinity x Thermocline slope	(-)	15.83	<0.0001
Sea-surface salinity x Halocline slope	(+)	9.42	<0.01
Halocline slope x Thermocline depth	(-)	5.13	<0.05
Halocline slope x Thermocline slope	(-)	3.87	<0.05

Table 2. Multiple regression model for the relationship between log Rhinoceros Auklet biomass and oceanographic variables (see Table 1 for list and explanation of methods).

Model F[17, 299] = 23.96, P < 0.0001, 57.7% variation explained.

Main effects:	Sign	F	P
Chlorophyll depth @ max	(-)	4.62	<0.05
Chlorophyll depth @ max ²	(+)	45.66	<0.0001
Chlorophyll maximum	(+)	29.31	<0.0001
Sea-surface salinity	(+)	20.81	<0.0001
Depth of 10°C	(-)	4.90	<0.05
Depth of 10°C ²	(-)	9.80	<0.01
Halocline depth	(-)	4.99	<0.05
Halocline slope	(+)	3.94	<0.05
Interactions:			
Chlorophyll maximum x Halocline slope	(+)	39.09	<0.0001
Chlorophyll maximum x Halocline depth	(-)	22.21	<0.0001
Chlorophyll maximum x Chlorophyll depth @ max	(-)	12.36	<0.001
Chlorophyll maximum x Sea-surface salinity	(-)	11.63	<0.001
Chlorophyll depth @ max x Halocline slope	(+)	9.70	<0.01
Chlorophyll maximum x Depth of 10°C	(+)	9.43	<0.01
Chlorophyll maximum x Sea-surface temperature	(-)	7.16	<0.01
Sea-surface temperature x Chlorophyll depth @ max	(-)	4.57	<0.05

DISCUSSION

The occurrence of the seabird predators principally at the edges of phytoplankton blooms was a marked feature apparent in our study. Seabirds, however, are not vegetarians. Rather, in the California Current, they feed principally on euphausiids and small fish, including juvenile salmon (e.g. Ainley et al. 1996a,b; Sydeman et al. 2001). The small fish graze phytoplankton or eat the smaller, grazing zooplankton. Given that the seabirds were feeding on grazing organisms, the question arises: Was the grazing — apparently most intense (or at least grazers most concentrated) at the periphery of surface and subsurface blooms — affecting the spatial extent of the phytoplankton blooms and, therefore, the availability of phytoplankton to organisms elsewhere in the region? In turn, the question arises, Assuming that the grazers (seabird prey) were most concentrated at bloom edges, what are the bio-physical mechanisms that enhance feeding efficiency there? These we believe are central question to be explored further by GLOBEC. Once the acoustic data along the sections are available, and which would show concentrations of zooplankton, answers to these questions can be pursued.

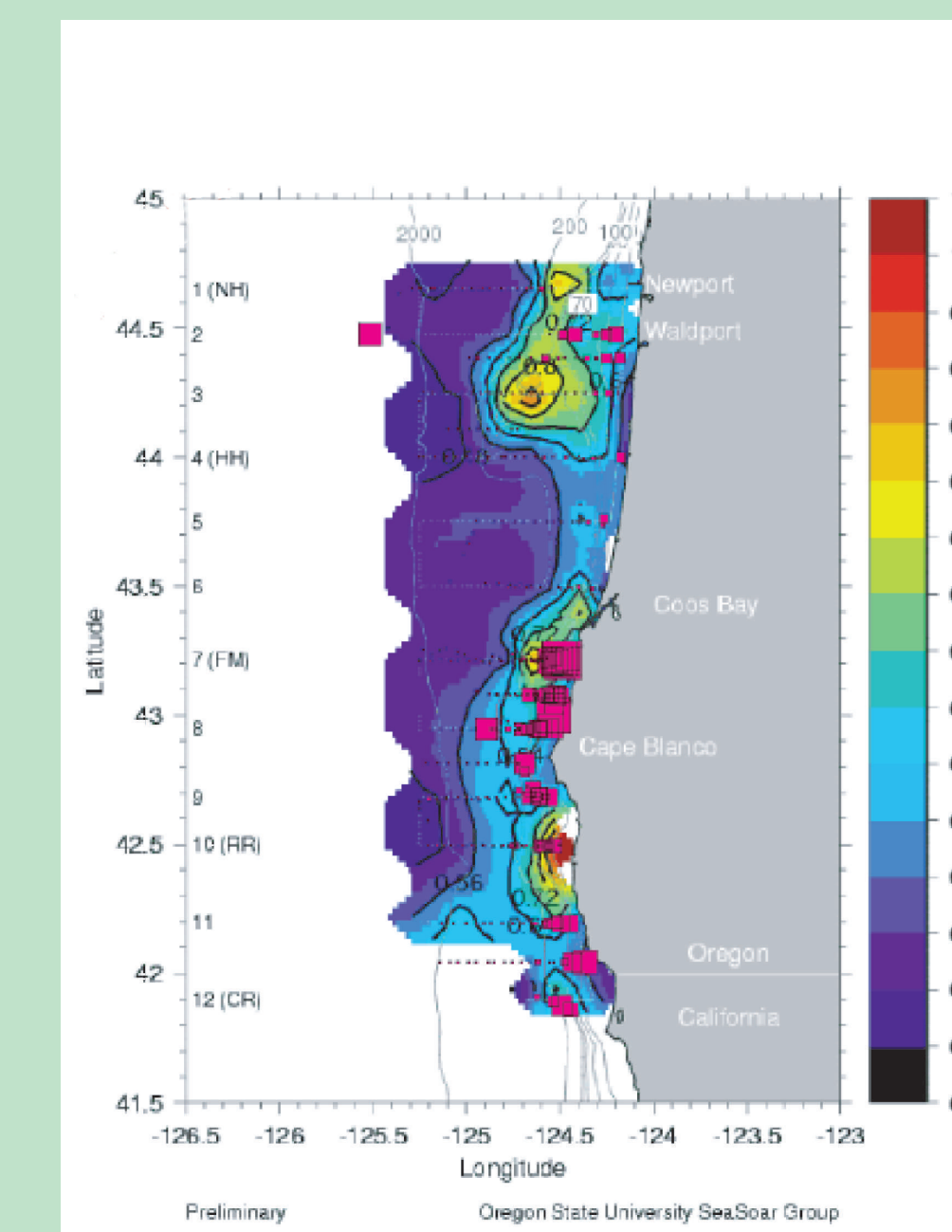


Figure 1. The 5-m depth fluorescence as determined by SeaSoar (preliminary analysis), overlain with the occurrence of Common Murres along GLOBEC cruise tracks. Murre symbols (red) are proportional to biomass on a logarithmic scale (largest >1000 kg/km²).

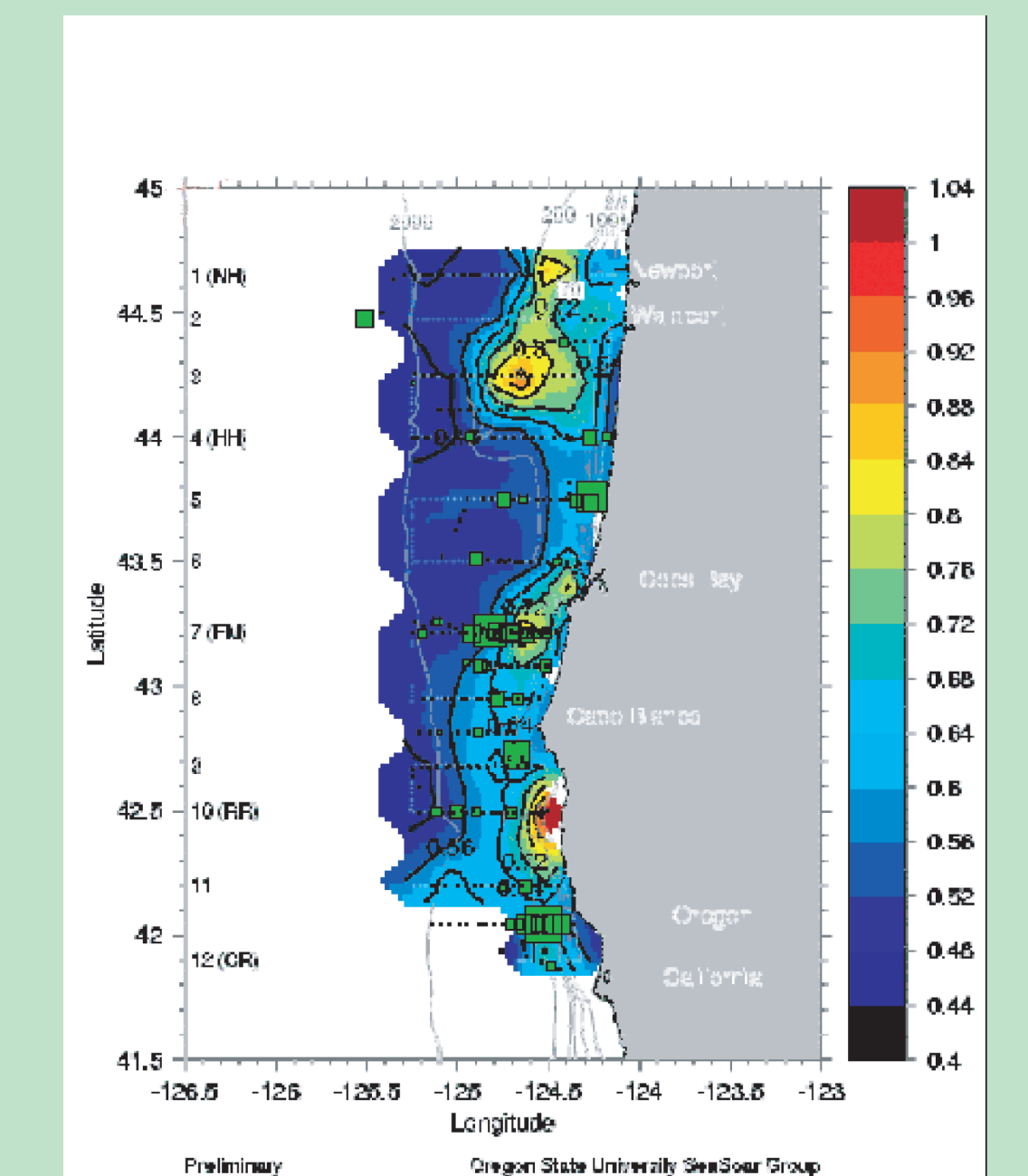


Figure 2. The 5-m depth fluorescence as determined by SeaSoar (preliminary analysis), overlain with the occurrence of Rhinoceros Auklets along GLOBEC cruise tracks. Auklet symbols (green) are proportional to biomass on a logarithmic scale (largest >1000 kg/km²).

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Table 3. Multiple regression model for the relationship between log Common Murre biomass and oceanographic variables (see Table 1 for list and explanation of methods).

Model F[17, 299] = 8.04, P < 0.0001, 31.4% variation explained.

Main effects:	Sign	F	P
Chlorophyll maximum	(+)	20.76	<0.0001
Chlorophyll maximum ²	(+)	18.41	<0.0001
Sea-surface salinity	(+)	8.39	<0.01
Depth of 10°C	(-)	7.71	<0.01
Thermocline depth	(-)	4.75	<0.05
Thermocline depth ²	(+)	5.57	<0.05
Interactions:			
Thermocline slope x Chlorophyll maximum	(+)	12.36	<0.001
Thermocline slope x Chlorophyll depth @ max	(+)	10.18	<0.01
Thermocline slope x Halocline slope	(-)	6.02	<0.05
Sea-surface temperature x Chlorophyll depth @ max	(-)	5.42	<0.05
Chlorophyll maximum x Chlorophyll depth @ max	(-)	5.26	<0.05
Depth of 10°C x Thermocline depth	(+)	4.26	<0.05

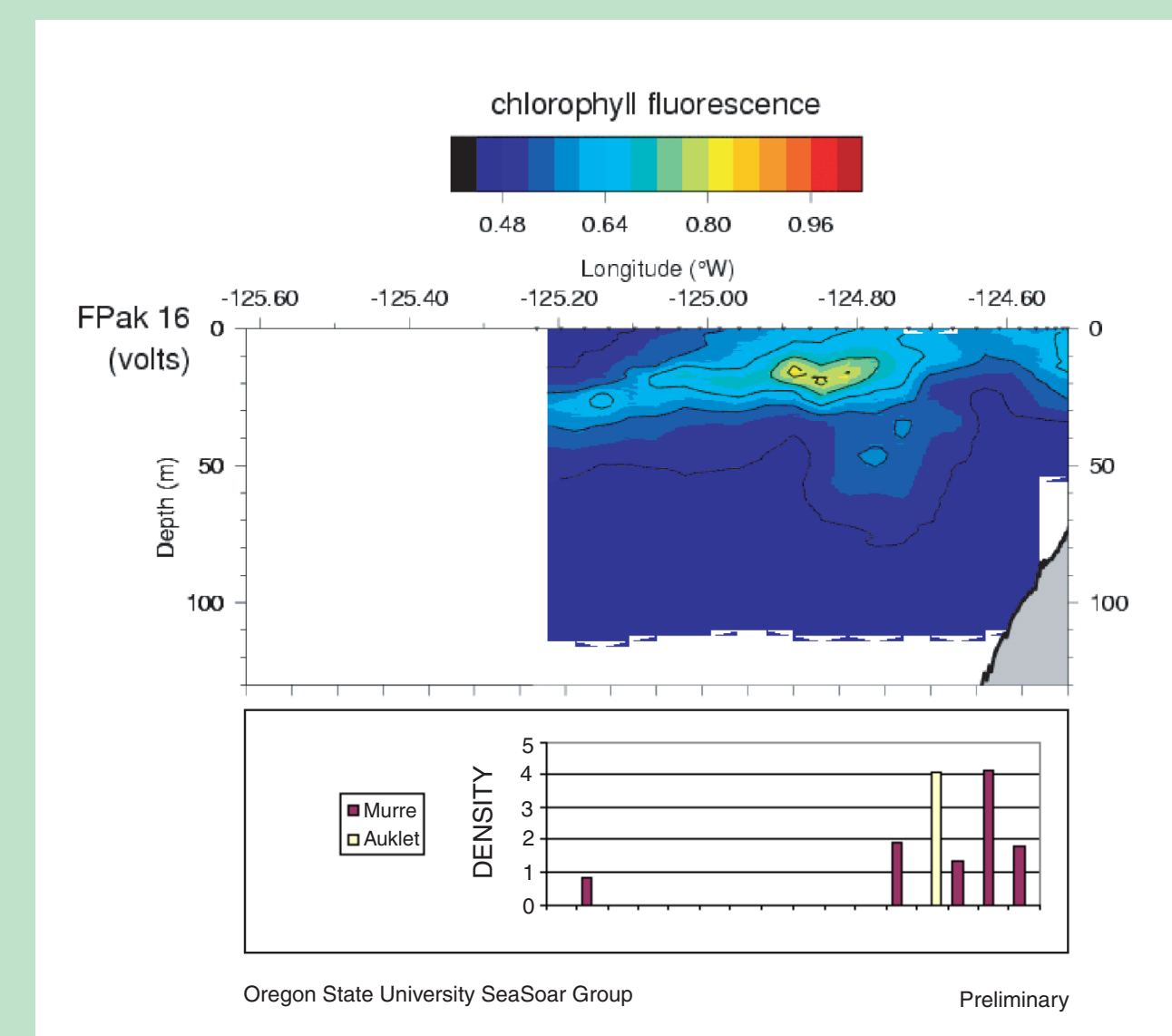


Figure 3. Ocean section along line 9 (near Cape Blanco) on 1 June when upwelling was at full intensity. Seabird density (birds/km²) compared with fluorescence.

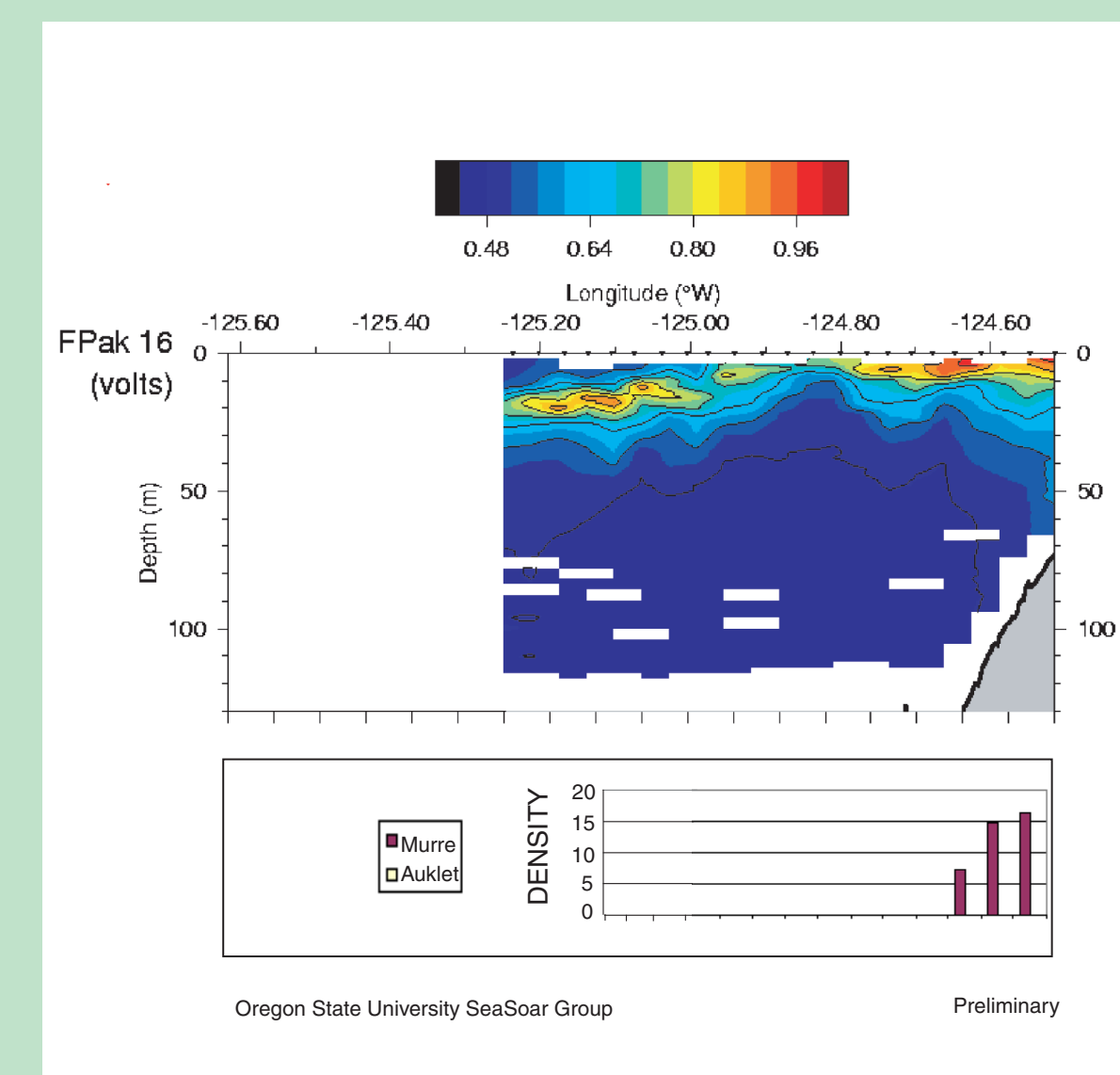


Figure 4. Ocean section along line 9 (near Cape Blanco) on 8 June when down-welling was in progress. Seabird density (birds/km²) compared with fluorescence.

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