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An Investigation of Relationships Between Odontocete Distributions and Zooplankton Abundances

by

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Abstract

During 01 June to 02 July 1993, the NOAA/NMFS/NEFSC Marine Mammal Investigation, Woods Hole, MA, undertook a shipboard survey of cetacean species' distributions and abundances on the eastern and southern edges of Georges Bank. During transects of the study area, concurrent physical and biological data were collected to examine characteristics of marine mammal habitat. Zooplankton communities were sampled during this survey by double oblique bongo tow. Cetacean sighting rates (animals h⁻¹) and mean group sizes within 20 km of bongo stations were compared with log₁₀ copepod density. Delphinid sighting rate increased and mean delphinid group size decreased, with increasing copepods m⁻³. Within delphinids, striped and common dolphin sighting rates exhibited an inverse relationship with copepod densities, and a positive relationship with copepod diversity. Mean common dolphin group size was negatively correlated with copepod diversity. Non-delphinid odontocetes were not related to copepod density, although sperm whale and beaked whale sighting rates were significantly correlated with euphausiid and chaetognath densities, respectively. Two-variable models for sighting rates of some odontocete species were found in which a plankton-derived variable made a statistically significant contribution to explaining variance. An understanding of zooplankton community structure is useful in understanding oceanographic characteristics of cetacean species' habitat.

Introduction

Effect of Physical Oceanography on food chains

Ecosystems are the sum of interactions between a great number of physical and

biological parameters. Temperature, salinity, nutrient concentrations, tidal influences, upwelling due to a variety of causes, the rotation and revolution of the earth are important factors in regulating primary and secondary production. Wind-driven transport processes have been suggested as the most important forcing function offshore the western coast of the United States (Smith and Brink, 1994). Wind, by affecting currents, affects nutrient distribution and thus regulates regions of seasonal primary production. Zooplankton densities are functions of these environmental parameters, and in turn, are a factor in food availability for predators.

Production processes of phytoplankton and zooplankton serve as links between physical phenomena and fish stocks (Mann, 1993). Vertical mixing, followed by stratification, often results in diatom blooms. Diatom productivity favors mesoplankton production. Mesoplankton production serves as food for commercially important fish stocks. Bathymetry exerts direct and indirect controls over seasonal and spatial patterns of plankton blooms (Perry and Dilke, 1986).

Thermal gradients, structural heterogeneity of the continental shelf, and persistence of hydrographic fronts at continental shelf margins are important factors in zooplankton production (Sabates, *et al.*, 1989). Water temperature and origin of water masses often affect copepod species' distributions (Atkinson, *et al.*, 1990). Individual species may serve as tracers of water temperature or water mass history. Species abundances may be correlated with water temperature.

Seasonal, seaward progression in spawning activity of fish species off Southwest Ireland was suggested to influence zooplankton distributions, which also influence fish larval behavior (Doyle and Ryan, 1989). A high level of spatial correlation exists between the occurrence of fish larvae and their copepod food source. Path analyses have been used to show significant correlations between zooplankton abundance and recruitment in some fish species in the North Sea (Pepin, 1990). Herring, cod and flatfish recruitment rates were associated with fluctuations in *Calanus* abundance.

Planktonic interactions with cetaceans

Marine mammals are best understood when viewed as part of an ecosystem. Species' distributions are products of a complex set of environmental interactions. One very important interaction of marine mammals with their environment is the selective pressure

thought to have triggered their evolution. Feeding ecology is likely the prime factor in the distributions and behaviors of cetaceans. Mesoscale oceanographic features affecting prey distributions may be important factors affecting cetacean distribution (Selzer and Payne, 1988). Study of relationships between the environment and cetacean species' distributions may aid in describing marine mammal habitat.

Oceanic chlorophyll distributions and concentrations have been suggested for use as a habitat descriptor for some species of marine mammals (Smith, *et al.*, 1986). Sightings of cetaceans were often in the vicinity of topographic relief and high chlorophyll concentrations, although some species (*e.g.* *Mesoplodon* sp. and *Physeter macrocephalus*) were associated with low chlorophyll concentrations. Relationships were found between sightings of certain cetacean species and the coefficient of variation of chlorophyll.

Right whale distribution in the northwest Atlantic is a function of availability of dense patches of *Calanus finmarchicus* (Wishner, *et al.*, 1988. Frontal features may play an important role in distribution patterns of right whales in the Great South Channel region between Georges Bank and Cape Cod (Brown and Winn, 1989.) Surface prey patches where right whales fed were dominated by the copepod species *C. finmarchicus*, *Pseudocalanus minutus*, or *Centropages* sp. (Mayo and Marx, 1990).

Little work has been done to investigate zooplankton parameters in odontocete habitat. Aggregations of cetaceans around the Kuril Islands has been attributed to high squid abundance in the region (Shuntov, 1993). High squid abundance may indirectly result from theorized high levels of zooplankton. But this hypothesis was not tested. Acoustic detection of relative planktonic biomass in the Mediterranean Sea suggested cetacean biomass was positively correlated with planktonic biomass (Viale, 1991). Sperm whales were found abundant in one region with high plankton densities.

To properly manage or protect species involved in or impacted by commercial fisheries, low variance estimates of species abundances and distributions are essential. To better effect this goal, a refined understanding of cetacean and other apex predator distributions from an ecosystem/community viewpoint is needed. Organizations such as the International Whaling Commission and the International Council for the Exploration of the Sea have issued recommendations that multi-species ecology should be investigated (IWC, 1992). A multispecies approach to understanding distribution of large marine predators, including cetaceans, should focus on oceanographic structure, prey species distribution, and density dependent habitat selection (Smith, *et al.*, In Press).

Feeding habits of selected cetaceans in the northwest Atlantic have been summarized (Waring, 1995). Overlap in distributions of cetaceans and potential prey were analyzed. Some regressions between prey abundance and cetacean sighting rates were significant. Diversity and abundance of prey fishes may be a function of zooplankton concentrations (Stone and Jessop, 1992). Distributions of fishes and cetaceans may thus be influenced by the distribution of thermal structure and zooplankton biomass (Wishner, *et al.*, 1988; Doyle and Ryan, 1989; Crawford and Jorgenson, 1990; Mayo and Marx, 1990). Measurements of zooplankton production may thus aid in understanding odontocete distributions. This paper examines relationships of zooplankton abundance and diversity with marine mammal distributions in the northwest Atlantic. The hypothesis that zooplankton abundance and diversity are useful in explaining marine mammal distributions will be tested.

Materials and Methods

During 1 June to 2 July 1993 a National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA/NMFS) shipboard cetacean census was conducted along the eastern and southern edges of Georges Bank, aboard the NOAA vessel Delaware II. During transects of the study area, (extending from the Scotian Shelf to Veatch Canyon), concurrent physical and biological data were collected to examine characteristics of marine mammal habitat. Cetaceans were sighted using 25X150 power binoculars. Survey protocol involved continuous effort from 0600-1900 EDST, with two observers scanning through binoculars, and a third observer (serving as data recorder) scanning unaided. Effort continued as sea state and weather conditions permitted.

Transects were designed to frequently traverse the shelf-break in a zig-zag pattern. At the end of each traverse, casts were made to determine hydrographic structure using a conductivity temperature depth bathythermograph (CTD). Casts were sent to a depth of 200 m or to within 10 m of bottom, whichever was greater. Cast data were received and archived on computer as casts were underway.

Periodically, zooplankton were sampled simultaneously with CTD casts using the double oblique Bongo tow method. Bongo stations were randomly selected at the end of transect lines. Tows were made using 303 μm mesh and 505 μm mesh nets. Surface temperatures were recorded at the 36 stations sampled, representing the variable BUCKTEMP in this study. A total of 36 stations were sampled. Stations covered a variety

of habitats (e.g. on-shelf/off-shelf, over canyon/inter-canyon). Of stations sampled, the last 18 were performed when adrift, due to mechanical failure of the vessel's slow-speed clutch. However, currents and wind drift were sufficient to maintain a 30° incline of the tow wire. Zooplankton samples were preserved for later analyses with a buffered 10% formalin solution.

In the lab, zooplankton samples were volumized and split, resulting in sub-samples of approximately 500 organisms. Sub-samples were then analyzed for taxa and abundance. Copepods were further analyzed to species level. Organism and copepod density (m^{-3}) were computed using split data and metered tow volume. For this study, abundances were log transformed, to compensate for potential curvilinearity.

Data from the 505 μm mesh net were used for this study. Two of these samples were discarded due to deterioration of sample. An analysis of relative abundance levels indicated high significance in the relationship between 505 μm and 333 μm samples ($505/333=0.544$; $p=0.002$). The resulting factor was applied to the 333 μm copepod and total organism abundance values for station 12 and 13, to yield expected 505 μm mesh values.

For copepods, a Shannon Diversity Index was calculated [$H' = -\sum p_i \log(p_i)$]. From the index, a measure of species abundance equitability, J , was computed as $J=H'/H'_{max}$; where H'_{max} is the value of H' computed with the same number of species, but equal p_i values (Cox, 1985).

CTD data were summarized as 4 variables in order to qualify thermal structure. Water masses were classed as 3 specific categories, (THERCLAS): 1) thoroughly mixed over the entire water column sampled = 0; 2) thermally stratified, with warm water overlying cooler water = +1; 3) thermally stratified, with a warm water mass underlying cooler water = -1. Hydrographic conditions of warm water underlying cool water suggests presence of a subsurface thermal front.

Additional hydrographic variables were 1) CTDMAX, maximum temperature over 200 m or cast depth; 2) CTDMIN, minimum temperature over 200 m or cast depth; and 3) CTDRANGE, the difference between CTDMAX and CTDMIN.

In addition to plankton and hydrographic variables, fixed geographic variables, bottom depth at station site (m) and latitude of station site, were examined for relationships with plankton and cetacean variables.

All recorded cetacean sightings were used, whether recorded during active search effort or sighted while diverting from track to further investigate prior sightings. Sighting

data were summarized as quantities representing total animals sighted within a ~~20~~⁴⁰ km square block, with bongo stations at center of blocks. These quantities were standardized for effort by dividing total animals seen within a given ~~20~~⁴⁰ km block by total number of hours on effort within the block. Relative whale and dolphin sighting rates were computed for 3 general groupings of taxa: 1) mysticetes, 2) Delphinidae, and 3) non-delphinid odontocetes. Block data were used when total effort within a block was 2 hours or greater. One block was discarded from analyses due to lack of CTD data, resulting in 31 sets of data thermal data.

When species were sighted in at least 50% of examined blocks, standardized sighting rates were calculated. Species found in 50% of blocks included the common dolphin (*Delphinus delphis*), striped dolphin (*Stenella coeruleoalba*), Atlantic white-sided dolphin (*Lagenorhynchus acutus*), pilot whales (*Globicephala* sp.), sperm whales (*Physeter catodon*) and beaked whales (*Mesoplodon* sp.). Mean group sizes of species by station were calculated as a function of total animals of a given taxa sighted, and total number of sightings of that taxa.

Cetacean data were analyzed for correlations with environmental parameters (Pearson's product-moment correlation coefficient; Sokal and Rohlf, 1981). Potential two-variable models using plankton data were evaluated using Proc Reg of the SAS program. Null Hypotheses were rejected when the probability of type II error ≤ 0.05 .

Results

The research cruise consisted of 2 components. Leg 1 sighting effort = 03 June to 11 June and Leg 2 effort = 16 June to 30 June. During Leg 1, a warm core ring was positioned along Georges Bank's southeastern edge. Sighting effort and bongo tows were conducted in cooler waters north of the ring (Fig. 1). During Leg 2, the warm core ring had moved south, and a second warm core ring occupied the region of cooler water during Leg 1. Sighting effort and bongo tows were performed in the interface between the southern warm core ring and cooler shelf water (Fig. 2).

Copepod abundance ranged from 10.9-1172 m³, while total zooplankton abundance ranged from 16.4-1189 m³. Copepod diversity (Shannon Index) ranged from 0.019-1.43, while equitability of abundance of species (*J*) ranged from 0.024-0.86. Surface temperature at bongo sites varied between 6.8-22.0°C, while temperatures recorded by the CTD were 3.9-22.0°C. Depth at sites ranged from 54 to 3000 m.

Log transformed zooplankton abundances and measures of zooplankton diversity were significantly correlated with both fixed (*e.g.* latitude, bathymetry) and transient (*e.g.* temperature) physical variables (Table 1). Copepod abundances were greater in northern regions of the survey, and abundance decreased in deeper waters. Greater water temperatures, as measured by the CTDMAX, CTDMIN and BUCKTEMP variables were present when copepod abundances were lower. Copepod abundances were elevated when sub-surface thermal fronts were present. Diversity in the copepod community was highest in southern, offshore regions with warmer water temperatures.

Sighting rates (animals h⁻¹) for delphinids, non-delphinid odontocetes, and mysticetes were correlated with biological or physical variables (Table 2). Mysticete sighting rates were greatest in northern areas at shallower depths, and when diversity in the copepod community was low. Non-delphinid odontocetes tended to be sighted more frequently in warmer waters, with sub-surface thermal fronts present. Delphinids were more prevalent in southern areas with warmer water, and off the shelf. Unlike mysticetes or non-delphinid odontocetes, delphinid abundances were significantly negatively correlated with zooplankton abundance, and positively correlated with copepod diversity.

Specific taxa were analyzed for relationships with physical and zooplankton variables when the taxa were sighted within 20 km of 16 or more bongo stations (½ of bongo stations with > 2 hours sighting effort within a ~~20~~⁴⁰ km block. Due to difficulty identifying *Globicephala* and *Mesoplodon* species at sea, these taxa were analyzed on a generic basis. Other taxa were analyzed by species.

Many significant relationships were apparent (Table 3). Sperm whale numbers were highest in deeper water, but were not correlated with physical variables or copepod abundances. Sperm whales tended to be sighted where euphausiid numbers were higher ($r=0.3600$, $P=0.04$). Beaked whale abundances were greater where surface temperatures were lower and sub-surface thermal fronts were present, but exhibited no correlation relationships with copepod abundance. However, beaked whales tended to be more abundant where chaetognath densities were low ($r=-0.3585$, $P=0.04$). Pilot whales did not exhibit significant correlations with any variables analyzed. White-sided dolphin abundances tended to be higher in cooler temperatures, but was not correlated with other physical or biological variables. Striped dolphins were found in warm, deeper water, with low copepod densities and high copepod diversity. Common dolphins also were found in deeper, warm water with low copepod densities and high diversity, and tended to be associated with presence of sub-surface thermal fronts. Both striped ($r=-0.5272$) and common dolphin ($r=-0.5219$) numbers

were greater in southern latitudes ($P=0.002$).

Table 4 — Mean mysticete group size was not correlated with temperature or zooplankton data (Table 4). Non-delphinid odontocete groups tended to be larger in warmer water, but were not related to copepod densities. However, delphinid group sizes were significantly correlated with many variables. Groups tended to be larger in warmer waters with greater vertical temperature range. Group size also tended to be greater when copepod densities were low, and diversity high.

Table 5 — When dolphin species were sighted within at least 16 blocks, group sizes were analyzed for correlations with zooplankton. Only common dolphins showed significant relationships with copepod density (Table 5). Mean common dolphin group sizes were greater when copepod densities were low and diversity high.

Table 6 — Models describing functional relationships between cetacean sighting rates (animals h⁻¹) and analyzed variables were investigated in order to identify 2-variable models in which at least one variable was plankton-based, and both made a statistically significant contribution to the relationship. Models were found relating mysticete, striped dolphin, Atlantic white-sided dolphin and pilot whale abundances to Shannon's diversity index and surface temperature (Table 6). Semi-partial correlation analysis (Thorndike, 1978) indicated the diversity index made an important contribution to explaining total variance. Models showing a relationship between copepod density and temperature range in the water column with sperm whale abundance, satisfied the requirement that both predictors be significant. A model explaining variance of beaked whale sighting rates as a function of copepod density and minimum temperature over cast depth also was significant for both variables. Semi-partial correlation analysis revealed the contribution of copepod density to explanation of variance in sperm whale and beaked whale 2-variable models was small.

Discussion

Significant relationships of copepod abundances with fixed geography and oceanographic variables are in agreement with other work on these topics (Holligan, 1981). Copepod diversity and abundance is known to be low in the Sargasso Sea, and within Gulf Stream features. High copepod abundances with low diversity in cooler waters surveyed during leg 1, and lower copepod abundance with high diversity in warmer waters surveyed during leg 2, likely resulted from presence of a warm core ring, rather than presence of a

secondary production "bloom" in northern regions. Thermal stratification with warm water underlying cooler water (THERCLAS=-1), suggests the presence of a thermal front. Copepod densities, negatively correlated with thermal class (THERCLAS), thus seem greater in regions of thermal fronts. Again, this finding agrees with prior studies.

The negative correlation of mysticete sighting rate and positive correlation of delphinid sighting rate with bottom depth are in agreement with general descriptions of mysticete species as inhabitants of shallow waters, and delphinids as inhabitants of shelf-break or deeper waters. The Cetacean and Turtle Assessment Program described right whales, humpback whales, fin whales minke whales, and white-sided dolphins as shelf inhabitants (CETAP, 1982). Off-shelf cetaceans included the sperm whale, beaked whale, pilot whale, Risso's dolphin (*Grampus griseus*), bottlenose dolphin (*Tursiops truncatus*); common dolphin, and striped dolphin. In this study, the sperm whale, common dolphin and striped dolphin sighting rates were significantly positively correlated with bottom depth, while white-sided dolphin sighting rates were negatively correlated with bottom depths. Again, this agrees with earlier studies (CETAP, 1982).

Bottom depth is the single best variable for describing variation in delphinid sighting rates within 20 km of bongo stations. But bathymetry is not variable on biological time scales. To understand ecosystem dynamics, we must look at variation in environmental variables.

Delphinid sighting rates are significantly correlated with both physical and biological parameters. High degree of correlation between physical and biological data raises the question, which variables are acting as causal factors for delphinid distribution? Prior studies have concentrated on cetacean distributions as a function of water thermal structure and depth (Selzer and Payne, 1988; Fiedler and Reilly, 1994). It is doubtful that ambient temperature is itself a primary causal factor in distributions of endothermic animals such as cetaceans. Temperature may act as a selective pressure on the physiology of the animal (e.g. evolution of blubber as thermal insulation). Temperature may also serve as a conveniently measured proxy for a variety of biological conditions. However, the search for nutrition is likely the most important causal factor regulating the distribution of cetaceans.

Zooplankton are important in trophic dynamics of odontocete prey. As such, abundances may serve as a proxy for relative abundance of prey fish in a region. Hypothetically, consumption of zooplankton by fish should result in decreasing levels of zooplankton as densities of fish increase. When fish abundances reach levels sufficient to support large groups of delphinids, copepod densities might then be low.

It might be argued that close proximity of some bongo stations to one another in the Northeast Channel and on the north edge of the warm core ring during leg 1 (Fig. 1) has artificially biased statistical significance of the correlation between copepod abundance and delphinid sighting rate. To test this hypothesis, correlation analyses were performed after dropping 4 stations from the data. These 4 stations were middle sites in trios of close stations. Once again, delphinid sighting rates (animals h⁻¹) were significantly correlated with log(copepods m⁻³), ($r=-0.48211$, $P=0.009$); and with Shannon's diversity index ($r=0.54153$, $P=0.003$). Further, comparison of copepods m⁻³ (Fig. 3) and delphinids h⁻¹ (Fig. 4) clearly suggests an inverse relationship between copepod abundance and delphinid sighting rate.

Lack of correlation between copepod abundances and mysticete sighting rates are surprising, given evidence for mysticete consumption of zooplankton. However, most mysticetes sighted in the study are considered piscivorous in the North Atlantic, rather than planktivorous (Waring, 1995).

Non-delphinid odontocetes, *e.g.* sperm whales and beaked whales, feed at greater depths than delphinids. As such, abundance or distributions of these species might not be reflected in zooplankton densities in the surface 200 m, which this study examined. Significant relationships of sperm whale and beaked whale sighting rates with euphausiid and chaetognath densities, respectively, merit further investigation.

Common dolphins and striped dolphin sighting rates are negatively correlated with copepod abundances, and positively correlated with copepod diversity. This finding indirectly suggests similar optimum habitat requirements between the two species. However, a spatial plot of striped and common dolphin sightings reveals only two regions along the eastern edge of Georges Bank where the species were found in proximity (Fig. 5). Further study might be done to investigate differences in copepod community composition between regions where striped and common dolphins are found exclusive of the other.

Significant negative correlation between copepod density and mean group size of common dolphins suggests copepod densities are low when prey fish abundances reach levels sufficient to support large delphinid groups. Food resources are patchy within the pelagic environment. If resources are abundant enough within patches to support a group, then group hunting or foraging may be more efficient than solo foraging (Krebs and Davies, 1987). Presence of larger foraging groups suggests greater abundance of resources, *e.g.* prey of common dolphins. Striped dolphins do not exhibit a copepod density/group size relationship in this study, perhaps suggesting differing timing of response between species to prey fish, and hence zooplankton densities. In another study, canonical correspondence

analysis showed no meaningful relation between school size and environmental variability (Fiedler and Reilly, 1994).

Inclusion of plankton-derived variables in significant two-variable models for mysticetes, sperm whales, beaked whales, pilot whales, striped dolphins, and Atlantic white-sided dolphins suggests zooplankton data are useful in understanding dynamics of cetacean distributions. In the beaked whale model, where copepod density contributes a semi-partial R^2 of 0.9%, the total R^2 of 38.1% ($P=0.001$) is an improvement over the 25.6% ($P=0.004$) of variance explained by the other variable, CTDMIN, alone.

Planktivorous species of fish or fish larvae may prefer distinct species of copepods or other zooplankton as prey. Characteristic zooplankton community structures might host characteristic communities of fish and squid. If so, odontocete prey distributions could be linked to unique copepod communities.

Following a bloom of primary production, phytoplankton biomass declines as secondary production of zooplankton increases, through consumption of phytoplankton (Fig. 6). Similarly, zooplankton biomass declines as fish and squid populations mature, or as they migrate into a region. Fish and squid abundances may decline as cetaceans populations increase following migration into a region. Timing of immigration of individual cetacean species into an area may be correlated with zooplankton community structure and diversity. Studies of zooplankton may then explain variations of trophic needs between species.

The current study is a "snapshot" of a 1 month period during the summer of 1993. Variations of zooplankton and cetacean population abundances between years were not considered. But results indicate further investigation of zooplankton/odontocete interactions is justified.

Overfishing has drastically altered fish community structure within the last century. The interaction between fish and whales is in a state of dynamic flux. Although copepod community composition and densities may exhibit variation between years (Colebrook, 1972), zooplankton community structure might serve as a background against which to measure variation in cetacean distributions. Cetacean species may inhabit identifiable ecological communities, whose differences can be illuminated and interpreted by an analysis of characteristic zooplankton structure. If so, it would be interesting to observe cetacean ecological interactions respond to factors little affected by man. More research into biological perspectives of community and ecosystem dynamics is needed.

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Table 1 -- Pearson's product-moment correlations of physical parameters with zooplankton parameters. DF=35; except BOTM, LAT, BUCKTEMP, where DF=36.

	log ₁₀ (Copepods/m ³)	
<u>Variable</u>	<u>Coefficient</u>	<u>P</u>
BOTM	-0.5407	0.0007
BUCKTEMP	-0.6838	0.0001
CTDMAX	-0.8169	0.0001
CTDMIN	-0.6811	0.0001
CTDRANGE	-0.6076	0.0001
LAT	0.5312	0.0009
THERCLAS	-0.4407	0.008

Shannon's Diversity Index

<u>Variable</u>	<u>Coefficient</u>	<u>P</u>
BOTM	0.3868	0.02
BUCKTEMP	0.8719	0.0001
CTDMAX	0.8726	0.0001
CTDMIN	0.7564	0.0001
CTDRANGE	0.6191	0.0001
LAT	-0.8032	0.0001
THERCLAS	0.6532	0.0001

Table 2 -- Correlations of physical and zooplankton parameters with number of animals sighted h⁻¹ effort within 20 km of bongo stations. DF=32 for zooplankton variables, BUCKTEMP, BOTM and LAT; DF=31 for hydrographic variables.

Delphinids			Non-delphinid odontocetes		
<u>Variable</u>	<u>r</u>	<u>P</u>	<u>Variable</u>	<u>r</u>	<u>P</u>
BOTM	0.5856	0.0004	BOTM	0.0718	0.70
LAT	-0.6039	0.0003	LAT	0.0087	0.96
BUCKTEMP	0.4036	0.02	BUCKTEMP	-0.3496	0.05
THERCLAS	0.3159	0.08	THERCLAS	-0.4857	0.006
CTDMAX	0.4958	0.005	CTDMAX	-0.2764	0.13
CTDMIN	0.3186	0.08	CTDMIN	-0.5696	0.0008
CTDRANGE	0.4774	0.005	CTDRANGE	0.1534	0.41
LOGCOPEP	-0.4954	0.004	LOGCOPEP	-0.1051	0.57
LOGORGAN	-0.4817	0.005	LOGORGAN	-0.0739	0.69
SHANNON	0.5457	0.001	SHANNON	-0.2989	0.10
J	0.5473	0.001	J	-0.2428	0.18

Mysticetes		
<u>Variable</u>	<u>r</u>	<u>P</u>
BOTM	-0.4154	0.02
LAT	0.4903	0.004
BUCKTEMP	-0.0227	0.90
THERCLAS	-0.2442	0.19
CTDMAX	-0.2345	0.20
CTDMIN	-0.0760	0.68
CTDRANGE	-0.3057	0.09
LOGCOPEP	0.2579	0.15
LOGORGAN	0.2489	0.17
SHANNON	-0.3682	0.04
J	-0.4765	0.006

Table 3 -- Correlations of zooplankton and physical parameters with number of animals sighted h' effort within 20 km of bongo stations, by species. Species must have been sighted within 20 km of at least 16 stations, to be included. DF=32 for zooplankton variables, BUCKTEMP and BOTM; DF=31 for physical variables.

Common Dolphins			Striped Dolphins		
Variable	r	P	Variable	r	P
LOGCOPEP	-0.5532	0.001	LOGCOPEP	-0.4506	0.01
SHANNON	0.5650	0.0008	SHANNON	0.4838	0.005
J	0.5622	0.0008	J	0.4927	0.004
BUCKTEMP	0.4800	0.005	BUCKTEMP	0.2583	0.15
CTDMAX	0.5075	0.004	CTDMAX	0.4136	0.02
CTDRANGE	0.3241	0.08	CTDRANGE	0.4286	0.02
BOTM	0.5474	0.001	BOTM	0.5840	0.0004
THERCLAS	0.4526	0.01	THERCLAS	0.2344	0.20

White-sided Dolphins			Pilot Whales		
Variable	r	P	Variable	r	P
LOGCOPEP	0.2369	0.19	LOGCOPEP	0.2426	0.18
SHANNON	-0.3215	0.07	SHANNON	-0.2227	0.22
J	-0.2229	0.22	J	-0.2916	0.11
BUCKTEMP	-0.5545	0.001	BUCKTEMP	0.0632	0.73
CTDMAX	-0.3512	0.05	CTDMAX	-0.1181	0.53
CTDRANGE	-0.0571	0.76	CTDRANGE	-0.0645	0.73
BOTM	0.1192	0.52	BOTM	-0.3337	0.06
THERCLAS	-0.0960	0.61	THERCLAS	-0.2963	0.11

Sperm Whales			Beaked Whales		
Variable	r	P	Variable	r	P
LOGCOPEP	0.0364	0.84	LOGCOPEP	-0.0964	0.60
SHANNON	-0.1281	0.48	SHANNON	-0.2438	0.18
J	-0.1133	0.54	J	-0.1622	0.38
BUCKTEMP	-0.1069	0.56	BUCKTEMP	-0.4317	0.01
CTDMAX	0.0760	0.68	CTDMAX	-0.3004	0.10
CTDRANGE	0.2975	0.10	CTDRANGE	0.0452	0.81
BOTM	0.5346	0.002	BOTM	0.0071	0.97
THERCLAS	-0.2160	0.24	THERCLAS	-0.4534	0.01

Table 4 -- Pearson's correlations of zooplankton and physical parameters with mean group size of animals sighted within 20 km of bongo stations. DF=31 for CTDMAX and CTDRANGE; DF=31 for others.

Delphinids

<u>Variable</u>	<u>r</u>	<u>P</u>
LOGCOPEP	-0.6602	0.0001
SHANNON	0.6451	0.0001
J	0.6067	0.0002
BUCKTEMP	0.5503	0.001
CTDMAX	0.6086	0.0003
CTDRANGE	0.4148	0.02

Mysticetes

<u>Variable</u>	<u>r</u>	<u>P</u>
LOGCOPEP	0.0030	0.99
SHANNON	-0.1747	0.47
J	-0.2291	0.35
BUCKTEMP	0.1801	0.46
CTDMAX	-0.1556	0.54
CTDRANGE	0.0421	0.87

Non-delphinid odontocetes

<u>Variable</u>	<u>r</u>	<u>P</u>
LOGCOPEP	0.1124	0.54
SHANNON	-0.1851	0.31
J	-0.1013	0.58
BUCKTEMP	-0.3430	0.05
CTDMAX	-0.3305	0.10
CTDRANGE	0.0361	0.85

Table 5 -- Pearson's correlations of zooplankton parameters with mean group size of selected delphinid species sighted within 20 km of bongo stations. DF=32

Common Dolphins

<u>Variable</u>	<u>r</u>	<u>P</u>
LOGCOPEP	-0.5159	0.02
SHANNON	0.6288	0.002
J	0.6403	0.002

Striped Dolphins

<u>Variable</u>	<u>r</u>	<u>P</u>
LOGCOPEP	-0.0371	0.89
SHANNON	0.0223	0.93
J	0.0408	0.88

Pilot Whales

<u>Variable</u>	<u>r</u>	<u>P</u>
LOGCOPEP	0.1649	0.42
SHANNON	-0.2384	0.24
J	-0.2808	0.16

White-sided Dolphins

<u>Variable</u>	<u>r</u>	<u>P</u>
LOGCOPEP	0.0721	0.77
SHANNON	0.2266	0.35
J	0.3712	0.12

Table 6 -- Examples of two-variable models for cetacean sighting rates (animals h⁻¹), in which zooplankton-derived parameters significantly contribute.

<u>Taxa</u>	<u>Variables in Model</u>	<u>P</u>	<u>R²</u> <u>(Semi-partial)</u>
Mysticetes	Shannon's diversity	0.0001	11.8%
	Bucket temperature	0.00003	33.6%
Striped Dolphins	Shannon's diversity	0.003	22.4%
	Bucket temperature	0.04	10.7%
Atlantic White-Sided Dolphins	Shannon's diversity	0.04	11.7%
	Bucket temperature	0.0009	29.1%
Pilot Whales	Shannon's diversity	0.0001	6.0%
	Bucket temperature	0.0002	38.2%
Sperm Whales	log(Copepods m ³)	0.05	0.9%
	CtdRange	0.01	20.0%
Beaked Whales	log(Copepods m ³)	0.02	0.7%
	CtdMin	0.0003	37.4%

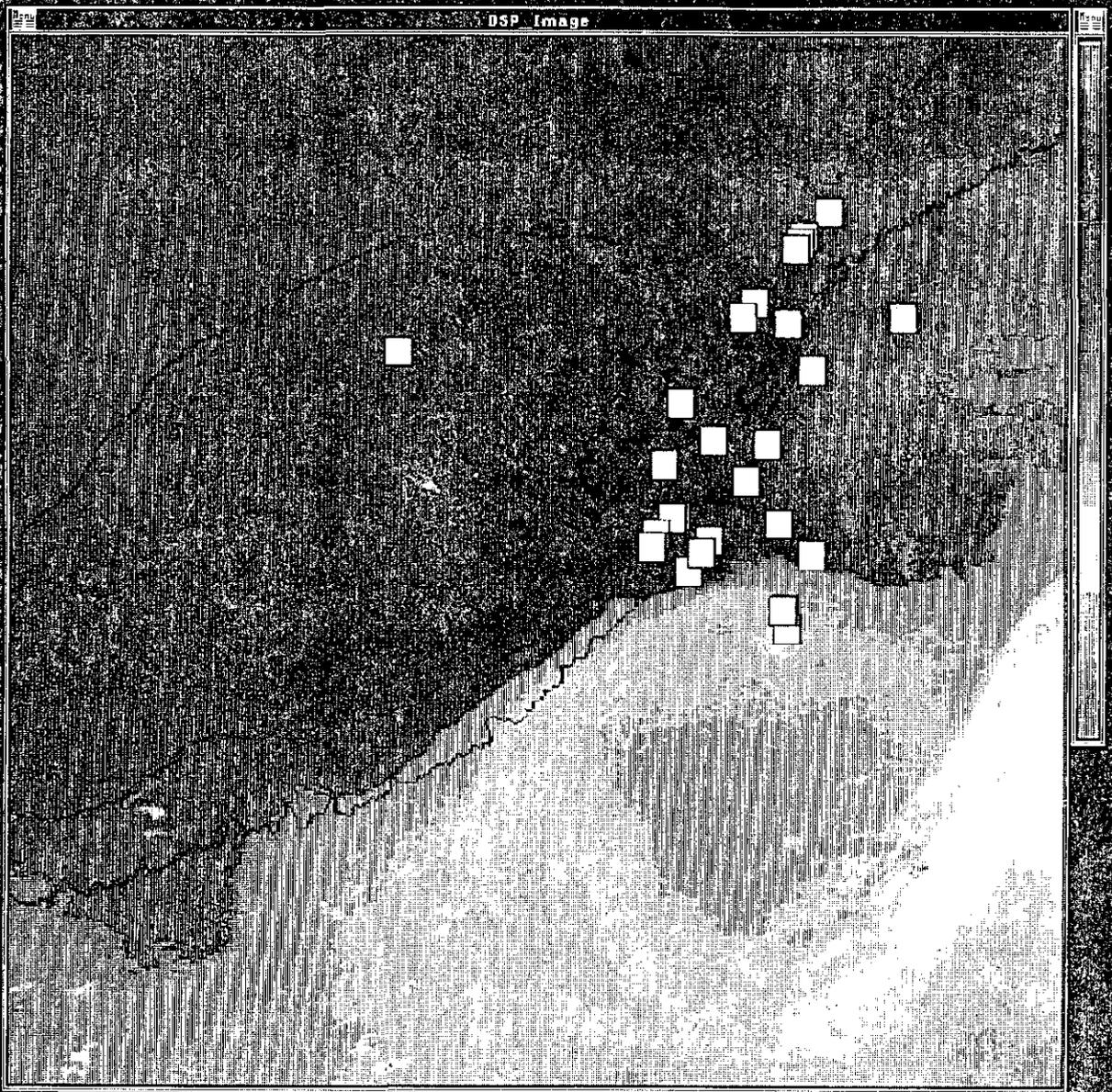


Fig. 1 -- Composite of Sea Surface Temperature (SST) images, 02-08 June. Bongo stations are depicted as white squares. Scale to right of image corresponds to temperature range of < 0 to $> 30^{\circ}\text{C}$. Bongo stations were primarily in cool water and along interface between cool and warm water.



Fig. 2 -- Composite of SST images, 23-28 June. Bongo stations are depicted as white squares. Bongo stations were located primarily in warmer waters.

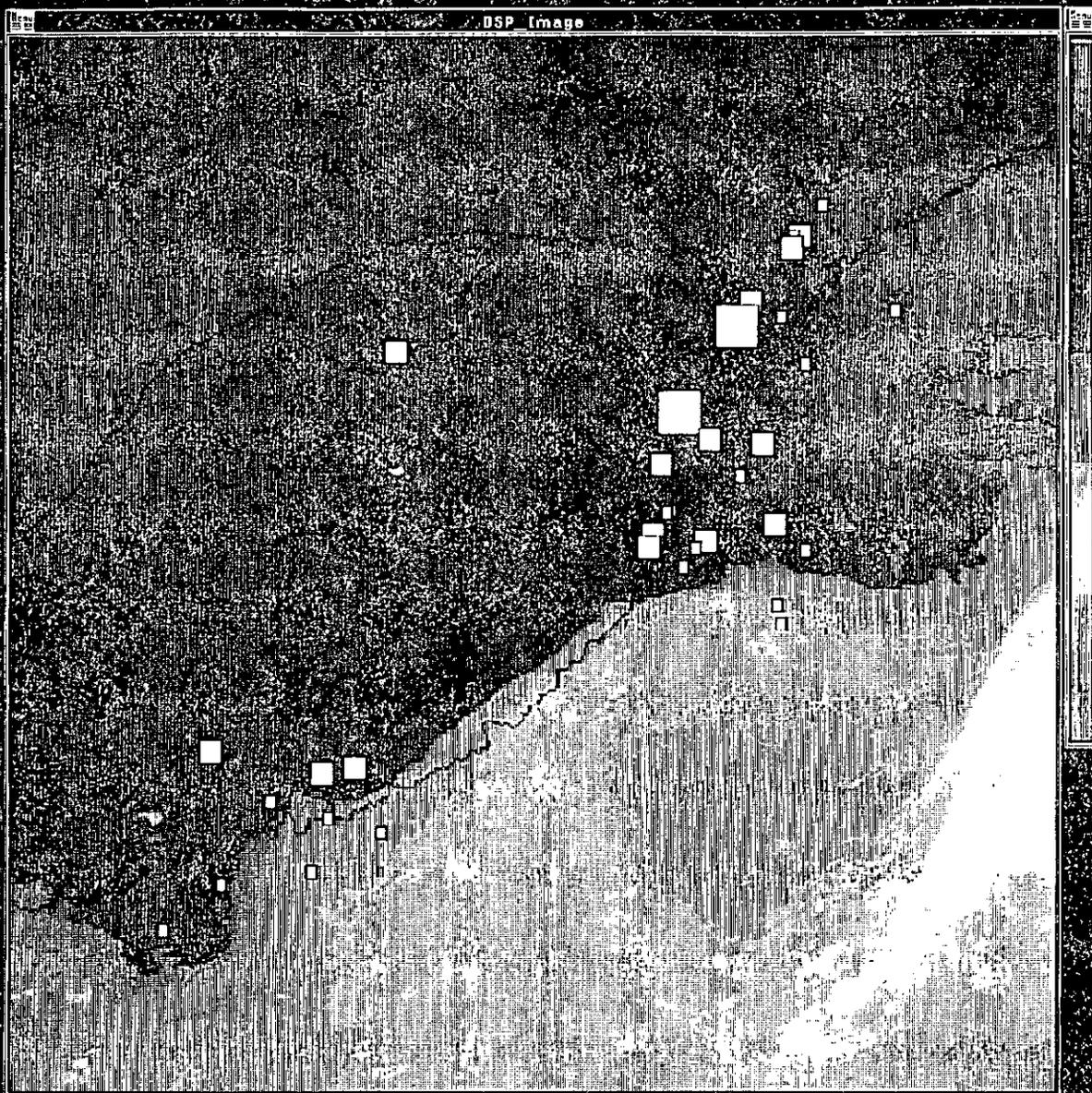


Fig. 3 -- Relative Copepod abundances at bongo stations. Smallest boxes = ≤ 200 copepods m^{-3} ; Medium boxes = > 200 and ≤ 500 copepods m^{-3} ; Largest boxes > 1000 copepods m^{-3} . No copepod densities were found in the range 500-1000.

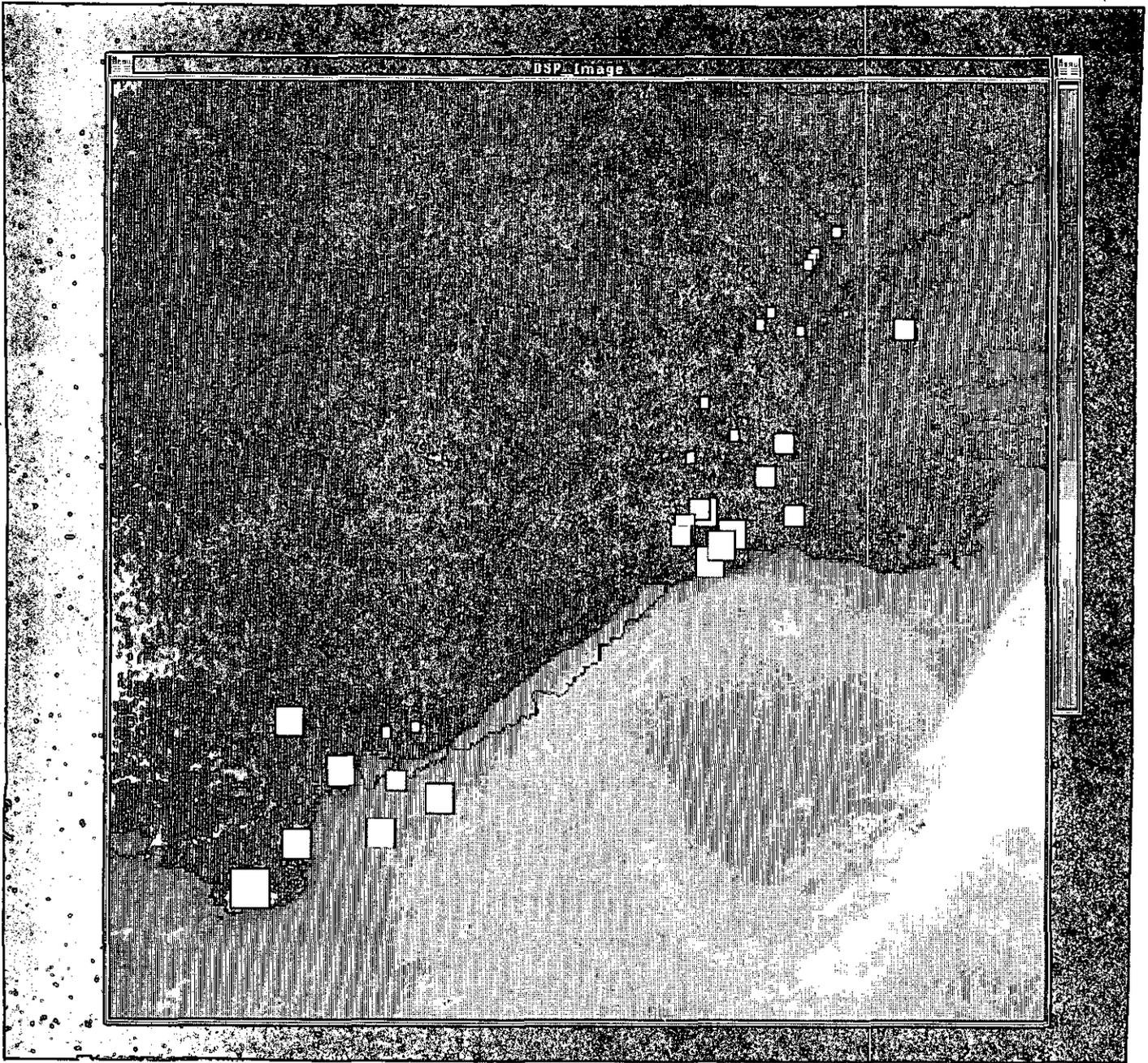


Fig. 4 -- Relative delphinid abundances at bongo stations. Smallest boxes = > 0 and ≤ 25 delphinids h^{-1} ; Medium boxes = > 25 and ≤ 40 delphinids h^{-1} ; Larger boxes = > 40 and ≤ 100 delphinids h^{-1} ; Largest box = > 100 delphinids h^{-1} .

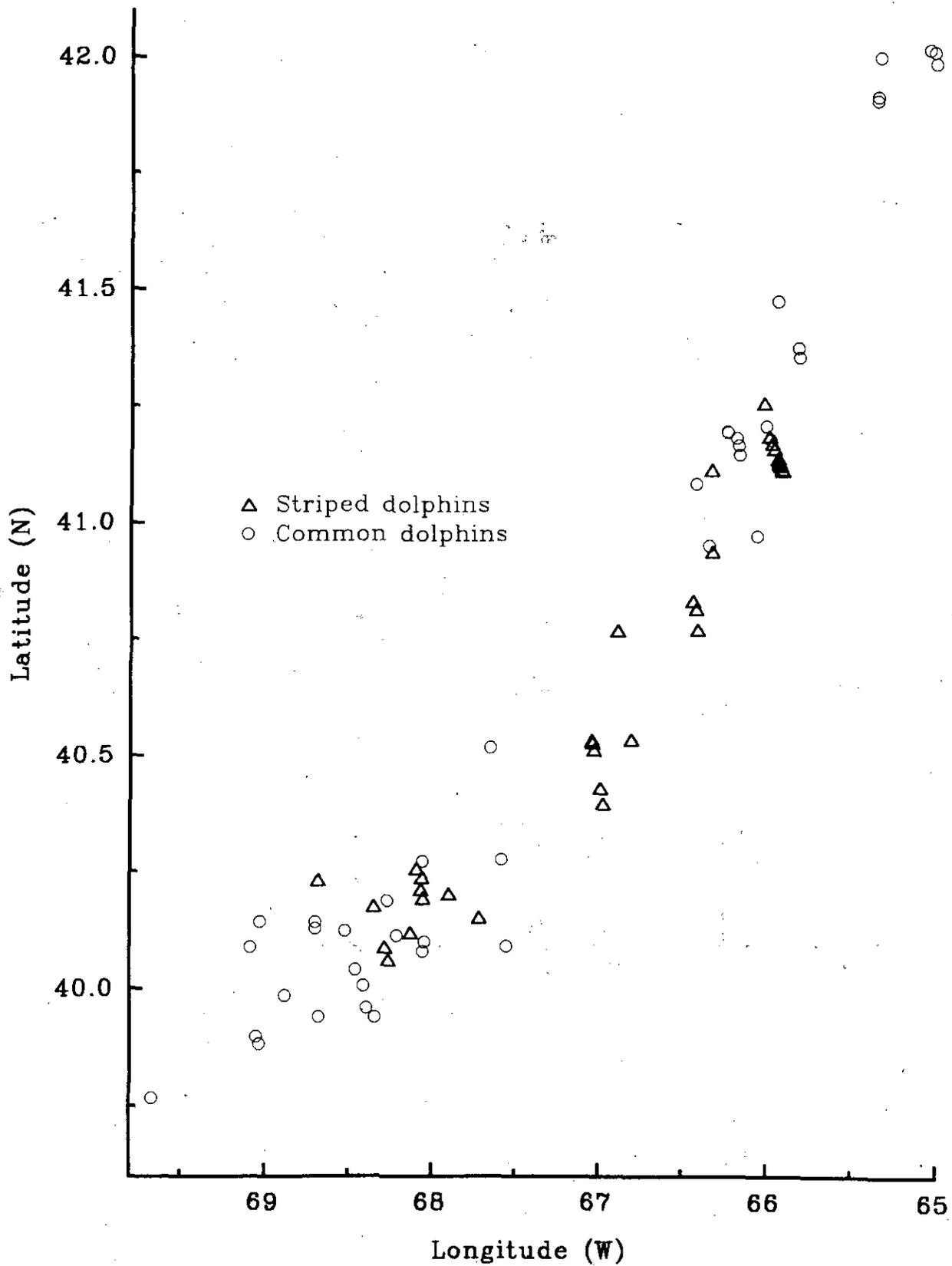


Fig. 5 -- Spatial location of common dolphin and striped dolphin sightings along the eastern edge of Georges Bank during the Delaware II cruise.

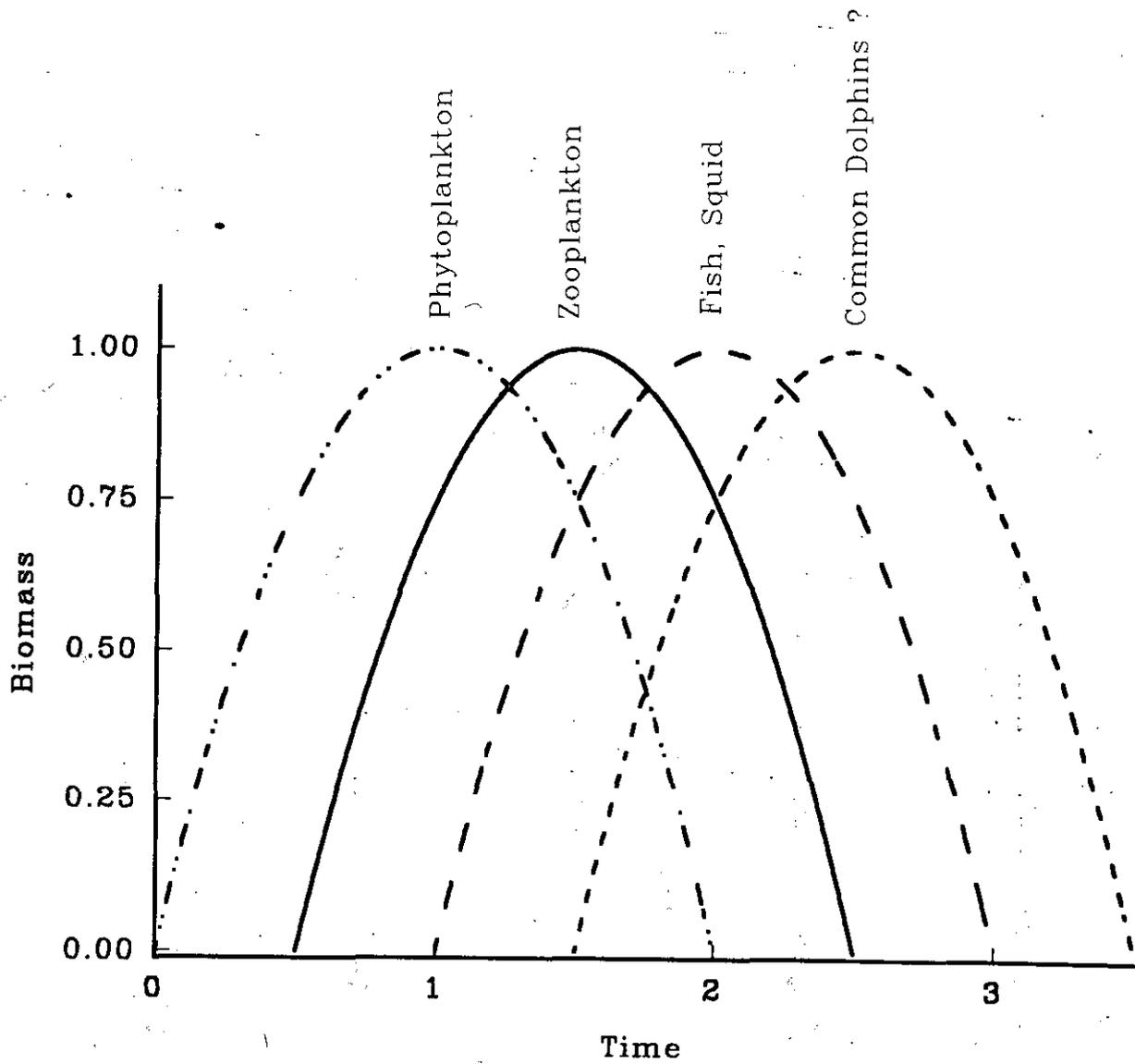


Fig. 6 -- Hypothetical biomass *versus* time at a fixed station on the eastern edge of Georges Bank.