PATTERNS IN SEABIRD OCCURRENCES OFF CANADA'S WEST COAST: A PILOT STUDY

by

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ABSTRACT

Data from 1850 ten-minute observation periods, recorded during six oceanographic voyages off Canada's west coast between October 1981 and October 1983, are analyzed in an attempt to determine relationships of observed seabird numbers to season, weather, salinity, temperature and distance offshore.

Chi-square analyses indicate a significant relationship exists between observed presence/absence of seabirds and season for sooty shearwaters, albatrosses, alcids, large gulls, storm-petrels and black-legged kittiwakes. The same technique also reveals a significant relationship between observed presence/absence of birds and weather for all species groups except storm-petrels.

Calculation of Spearman's coefficient of correlation between salinity, temperature, and distance offshore and observed numbers of birds gives no indication of a general trend although certain species groups were significantly correlated to one or more environmental variables at different times of year. Leach's and fork-tailed storm-petrels, combined as storm-petrels, show no correlation with any of the selected variables. The albatross species

group, mainly black-footed albatrosses, are significantly correlated only with temperature in March 1982.

Tests of distances to which small floating targets (simulating seabirds) remain visible after discharge from a depating ship suggest that target size, gray tone (or colour), and presence of white caps are significant sources of variation. Variations in these observability distances bias estimates of seabird populations towards higher estimates for large, light toned birds observed during calm conditions. Future work towards solution of this problem, possibly by determination of an observability coefficient for each species, is recommended.

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TABLE OF CONTENTS

TITLE PAGE..i

ABSTRACT...ii

TABLE OF CONTENTS...iv

LIST OF TABLES..vi

LIST OF FIGURES...viii

ACKNOWLEDGEMENTS.. xi

CHAPTER 1 INTRODUCTION..1

1.1 STATEMENT OF PROBLEM.....................................6

1.2 STUDY AREA...8

1.3 SCOPE AND LIMITATIONS...................................11

1.4 OBJECTIVES..15

CHAPTER 2 METHODOLOGY.......................................16

2.1 SELECTION OF VARIABLES..................................16

2.2 DATA COLLECTION...20

2.2.1 Transect Routes. 20
2.2.2 Collection of Oceanographic Data...22
2.2.3 Collection of Weather Data 22
2.2.4 Collection of Seabird Observation Data 23

2.3 VISIBILITY EXPERIMENTS..................................27

2.4 PREPARATION OF DATA FOR ANALYSIS 32

2.4.1 Data Merging.......................32
2.4.2 Frequency Analysis.................33
2.4.3 Species Groups Defintion...........35
2.4.4 Abundance Classes Definition.......36
2.4.5 Trip and Season Definition.........37
2.4.6 Definition of Survey Areas.........38

2.5 DATA ANALYSIS....................................40

CHAPTER 3 RESULTS....................................43

3.1 GRAPHICAL ANALYSIS FOR PATTERN DETECTION.....43

3.2 STATISTICAL ANALYSIS 45

3.2.1 Correlation of birds with offshoreness........................45
3.2.2 Correlation of birds with salinity.48
3.2.3 Correlation of birds with temperature.........................48
3.2.4 Species group to season relationship........................49
3.2.5 Species group to weather relationship........................50

3.3 SUMMARY.......................................56

CHAPTER 4 DISCUSSION.................................57

4.1 APPARENT PATTERNS............................57

4.2 INFLUENCE OF SEASON AND WEATHER..............60

4.3 CORRELATIONS..................................61

4.4 SUPPORT OF HYPOTHESES.........................67

4.5 WEAKNESSES AND UNRESOLVED PROBLEMS...........69

4.5.1 Difficulties of counting birds at sea..............................71

4.6 RECOMMENDATIONS FOR FUTURE WORK..............77

BIBLIOGRAPHY...83

APPENDIX...88

LIST OF TABLES

TABLE		PAGE
Table 1	Variables and their code equivalents for which data was collected during ten minute observation periods.	18
Table 2	Assignment of values for weather variables, visibility, wind and precipitation, based on observed conditions.	23
Table 3	Mean distances (meters) at which targets (cans) disappeared from sight during several different combinations of observer height, target size and target gray tone tabulated with number of observations (n) and standard deviation (s). May/82.	30
Table 4	Mean distances (meters) at which targets (balloons) disappeared from sight during several different combinations of wind, observer height, target size and target gray tone tabulated with number of observations (n) and standard deviation (s). May 1985.	31
Table 5	Example of results from frequency analysis of seabird observations for trip 1, October 1981.	34
Table 6	Abundance classes with numbers of observations in each class, by species group all trips combined. N=1850.	37
Table 7	Derivation of trip and season from year and month.	38
Table 8	Derivation of areas with descriptions....	39

Table 9 Spearman rank correlation coefficients (rs) of species-groups on salinity, temperature and area, by trip. Data base excludes two counts greater than 2000 and is limited to weather conditions when wind was less than 15 knots (1413 observations out of 1851). @ signifies a total lack of observations of a species from the study area, no meaningful correlation possible. 52

Table 10 Results of chi-square analyses for existence of relationships between presence/absence of birds, by species groups, and the two nominal variables; season and weather. There are four season categories, four weather categories and two categories for presence/absence; therefore degrees of freedom = (2-1)*(4-1) = 3 for both species groups and season and species groups and weather. N = 1101. 55

Table 11 List of common names of seabirds used as variables and their equivalent scientific names (Harrison, 1983). Appendix........ 89

LIST OF FIGURES

FIGURE		PAGE
Figure 1:	Map of western North America and part of the northeast Pacific ocean showing the study area outlined, with generalized transect route indicated.	13
Figure 2:	Satellite images of surface temperatures off the coast of Vancouver Island, October 1983.	14
Figure 3:	Route followed by CSS Parizeau May, 1982.	21
Figure 4:	Normal positions of observer for birdwatches on board the ships Parizeau and Endeavour during trips to Station P..	26
Figure 5:	Sketch of area surveyed during a 10 minute period.	26
Figure 6a, b:	Explanatory diagram for visibility tests	28
Figures 7-12:	Block chart of mean species counts per 10 minutes, in lat/long cells. Sums of the six species means are below bars.	
	Trip1. .... Appendix........	90
	Trip2. .... Appendix........	91
	Trip3. .... Appendix........	92
	Trip4. .... Appendix........	93
	Trip5. .... Appendix........	94
	Trip6. .... Appendix........	95

Figures 13-18: Bar graphs of mean species counts per 10 minutes, in areas ranked by distance offshore (3=farthest offshore).
Trip1............... Appendix........ 96
Trip2............... Appendix........ 97
Trip3............... Appendix........ 98
Trip4............... Appendix........ 99
Trip5............... Appendix........ 100
Trip6............... Appendix........ 101

Figure 19-24: Block charts of mean species counts per 10 minutes, in sal/temp cells. Sums of the six species means are below bars.
Trip1............... Appendix........ 102
Trip2............... Appendix........ 103
Trip3............... Appendix........ 104
Trip4............... Appendix........ 105
Trip5............... Appendix........ 106
Trip6............... Appendix........ 107

Figure 25: Pie charts showing mean species counts per 10 minute observation, by trip and area; pie fractions indicate species' contribution relative to total per observation; log[diameter] of inner circle is proportional to mean total per observation for comparison of trip/area cases............... Appendix........ 108

Figure 26: Effect of wind speed on visibility of small objects (balloons) on the sea surface. .... Appendix........ 110

Figure 27: Effects of object diameter on visibility of small objects (balloons) on the sea surface, under constant wind, swell and sea conditions. .... Appendix........ 111

Figure 28: Effects of gray tone on visibility of small objects (balloons) on the sea surface, with constant conditions of size, observer elevation, wind, swell and sea. .... Appendix........ 112

Figure 29: Effect of observer height above sea level on visibility of small objects (balloons) on the sea surface. ....Appendix........ 113

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"No man is an island, entire of itself."

John Donne, 1623.

CHAPTER 1

INTRODUCTION

Interest in the distribution and abundance of pelagic biota, particularly birds and fish, appears to have increased substantially over the past decade (cf. Lockley, 1974; Bourne, 1976; Dixon, 1977; Devillers, 1977; Tanaka & Kajihara, 1979; Briggs & Hunt, 1981; Vermeer, Robinson, Campbell, Kaiser & Lemon, 1983; Blake, Tasker, Hope Jones, Dixon, Mitchell & Langslow, 1984; Prince & Francis, 1984). The motivation for this interest has been derived from two sources: (i) concern for potential adverse environmental impacts associated with increasing oil and gas exploration and extraction activities on the continental shelves (e.g. North Sea, Hibernia and the Gulf of Mexico) and (ii) the declaration of exclusive economic zones, extending national jurisdiction 320 km offshore, primarily for management of fisheries resources and seabed minerals.

Records of offshore occurrence of birds date back at least to Columbus, for whom the sighting of coastal birds near the West Indies was a welcome sign that his ships might be approaching land after a long and arduous voyage fraught with the threat of mutiny. Whalers and deep sea fishermen throughout history often used the presence of certain species of seabirds as indicators of quarry. Only within the last several decades, however, have descriptions of abundance and distribution of pelagic birds become more systematic. Much of the work in this field, exemplified by Dunbar (1951), has originated with British researchers concerned particularly with the North Atlantic and the North Sea. Since the 1950's papers concerning those areas have been principally of two types, either anecdotal accounts or species specific studies dealing most frequently with bioenergetics (e.g. Prince & Francis, 1984). Exceptions to this trend have consisted of efforts to document and map generalized distributions of all or a broad range of seabirds within a particular ocean region (e.g. Brown, Nettleship, Germain, Tull, Davis, 1975; Bourne, 1978; Brown, 1978; and Wattel, 1978) and some research designed to determine cause and effect relationships between seabird distribution patterns and environmental conditions. The pioneer study representing the latter is that of Salomonsen (1965) who attempted to relate geographic distribution of fulmars to "delimiting zones of the marine environment", defined essentially by temperature patterns of the North Atlantic sea surface. Minor research efforts have investigated various impacts of human activities on seabirds, such as alcid mortality due to gill-net fishing (Carter & Sealy, 1982).

A similar pattern in research trends appears to have developed in other ocean areas. As in the North Atlantic, investigations directed at determining causal relationships underlying avian distribution patterns have generally been infrequent.

The North Pacific, although as critical in North Hemispheric marine bird biogeography as the North Atlantic, has received relatively little attention. Indeed, most seabird research in this region has been concentrated within the last fifteen years. Prior to 1970, descriptions of the distribution and abundance of pelagic birds were based on opportunistic observations (e.g. Miller, 1940; Martin, 1942; Yocom, 1947; Kenyon, 1950; Kuroda, 1955 and Poole, 1966) although McHugh's (1955) analysis of black-footed albatross distribution is an exception. More recent research has addressed the problem of obtaining data of sufficient quality to provide statistically reliable conclusions. It appears that one of the driving forces behind this shift toward more rigorous investigations in the northeast Pacific has been the "Outer Continental Shelf Environmental Assessment Program" initiated by the United States government in response to the Alaskan oil development. The more significant papers from this era are Sanger (1970) and Wahl (1975) who focused their attention on the offshore zone of Washington and Oregon, and Weins, Heinemann & Hoffman (1978) who attempted to define community structure, distribution and interrelationships of marine birds in the Gulf of Alaska.

Unfortunately, similar studies off Canada's west coast are virtually non-existent. The only exceptions appear to be an examination of pelagic seabirds in Hecate Strait and Queen Charlotte Sound by Vermeer & Rankin (1984) and the atlas by Vermeer et al (1983) which, although primarily of the nearshore zone, does include a limited amount of pelagic data. A major weakness of almost all studies of the distribution and abundance of pelagic birds off the west coast of Canada is that there have been few attempts to determine correlations between seabird occurrences and environmental factors.

As attention is increasingly directed towards the food and mineral resources of the world's coastal and offshore regions, many large resource exploitation projects will be planned and may require impact assessments. Oil and gas exploration activity has been increasing off Canada's west coast and the discovery there of a commercially viable field is a good possibility. Because seabirds are one of the most visible and easily monitored elements of the complex marine ecosystem knowledge of their distribution patterns and their possible correlations with environmental conditions should enable more sophisticated prediction of undesirable impacts and contribute to strategies for impact reduction.

Seabirds are directly and adversely affected by many of mankind's activities; fishing, oil spills, breeding and non-breeding habitat alienation, and general environmental alteration. The impact of some of these events might be significantly reduced by only slight changes in the position or timing of the event. The decision that an event in place A and time T1 will have less adverse impact than the same event in place B at time T2, will be most reliable if supported with tested research.

Although considerable research has been completed with regard to seabirds at or near nesting sites during breeding season much less effort has been focussed on seabirds within the study area during other seasons when they are away from colony sites. Some of the current knowledge gaps which hamper well supported decisions would be alleviated by information on overwintering distribution patterns, and an understanding of the correlations between oceanographic factors and bird occurrences.

1.1 STATEMENT OF PROBLEM

This research attempts to fill some of those apparent data gaps by: (i) determining the existence and nature of pelagic seabird abundance patterns off part of Canada's west coast and (ii) identifying correlations between those patterns and selected environmental factors. In addition, it explores a methodology for these tasks and recommends approaches to future investigations of this nature.

While seabird occurrence patterns may not always be apparent, their presence may be revealed by analysis of observation data. For this thesis, preliminary research in the Barkley Sound area during 1979 and again in 1981, combined with a review of Vermeer's pelagic data of August 1981 (pers. comm.) provided an expected species list. To this list were added assumed key locational and environmental factors: date, time, position, salinity, temperature and weather. It was hoped that seabird patterns could be related to spatial and temporal variations of these factors.

Expanding point two above requires consideration of both the factors which could influence seabirds and methods for detecting relationships between seabirds and those factors. The literature suggests that concentrations of birds in feeding flocks are often localized over zones of upwelling. These zones predictably have surface temperatures lower than surrounding water masses. Salinity on the other hand is usually higher in upwelled water than in the surrounding ocean (Thomson, 1981). Upwelling brings nutrients to the surface, where the resultant phytoplankton increase triggers a reaction of increases up the food chain. Upwelling may also physically transport food resources attractive to seabirds into their foraging zone at or near the surface. Salinity and temperature may, therefore indicate potential seabird foraging zones.

Other factors such as distance to breeding sites, distance offshore, bottom topography, season, past and present weather and concentrations of food may also influence the distribution patterns of seabirds.

1.2 STUDY AREA

The study area is a small section of the northeast Pacific Ocean extending westward from Vancouver Island to 145°W and lying between 48 and 52°N, Figure 1. The area was chosen primarily because access to it was available via oceanographic research vessels. However, the region does have intrinsic features which are desirable for a pilot study.

Biogeographically, it cuts across a section of the northern hemispheric ranges of several several species of seabirds, the sooty shearwater in particular. Other species (e.g. black-legged kittiwake) pass through the area during pre- and post-breeding migrations to or from arctic breeding sites. Many species, especially alcids (e.g. tufted puffin, Cassin's auklet, rhinoceros auklet, common murre) breed at nearby major colony sites and not only forage within the study area during or immediately after breeding season but also overwinter there.

The area also provides a desirable range of temporal and spatial variation in oceanographic conditions. The abundance patterns of seabirds off the west coast of Canada may be correlated with the position of water mass boundaries or other features resulting from complex oceanographic conditions such as the presence of a low salinity, relatively cool surface layer at the mouth of Juan de Fuca Strait or the recent northward thrust of El Nino (1981-83) into the study area, an intrusion of warmer than usual water. These thermal features are recorded by weather satellites whose data are available and easily converted into images from which the position of sea surface temperature patterns (Figure 2) may be monitored. If a correlation between sea surface temperature and seabird abundance were found then satellite imagery could be used as an aid in identifying probable zones of seabird concentrations on an almost daily basis.

Physically the area contains a bathymetric profile from the edge of land to near the centre of the Gulf of Alaska and crosses three distinct zones; shallow shelf, transition and deep pelagic. Seabird abundance patterns may be related to either depth or distance offshore. In either case these subareas provide useful criteria for data sorting and further analysis. Review of other research suggests that birds are generally most abundant over the shallow shelf and least abundant in the pelagic zone, although certain species form exceptions to this trend. The presence of definable depth subareas was therefore considered a desirable feature of the study area.

The major seabird breeding colony within the study area is at Triangle Island. Smaller, but significant colonies occur at Solander Island, Cleland Island, Cape St. James and near Cape Flattery. Of an estimated population of 12 million marine birds breeding in the northeast Pacific region, approximately 1/10 use sites on Canada's west coast, including 720,000 Cassin's auklets at Triangle Island, representing 40% of world population of that species (Vermeer et al, 1983). The presence of these large colonies supports the choice of this study area on the basis of its importance as a forage-resource hinterland for the breeding colonies and as the most immediate area to be utilized during post breeding dispersal and later by overwintering birds.

The advantages of access to the study area via oceanographic research vessels were manifold: free passage, a very satisfactory observation platform, coincident collection of oceanographic information, for example.

Data were collected on six oceanographic voyages to Ocean Weather Station P (145°W 50°N) onboard ships of opportunity from the Institute of Ocean Sciences (IOS). Bird observations, consisting of individual species counts per ten minute intervals, were recorded along with environmental conditions. After each voyage data from the ship's oceanographic log were merged with the seabird record. All but one voyage followed the route shown in Figure 3. The October 1983 trip returned directly to Victoria along the same route as the outbound leg to Station P.

1.3 SCOPE AND LIMITATIONS

Reducing the scope of the research to manageable proportions required that the focus be restricted to a small subarea of the northeast Pacific while still providing an overview of seabirds in both coastal and offshore waters combined with coincident records of environmental data. These requirements lead to the selection of the area noted above.

A second more practical limitation was imposed by the availability of ships of opportunity which would traverse a suitable area. Since the removal of the Canadian weather ships at the end of 1980, the Institute of Ocean Sciences has made several trips to Station P collecting oceanographic data along established transect routes to extend the time series initiated during the time of the weather ships. The availability of passage on the those ships strongly influenced the choice of study area. No other area offered such access in combination with a similar range of environmental conditions.

Because of limited time and money, this research should not be considered a definitive work but rather a pilot study. In consequence, results have been discussed from the perspective of providing insights into apparent patterns and possible correlations between distribution patterns and plausible controlling environmental factors and concludes with recommendations for future work.

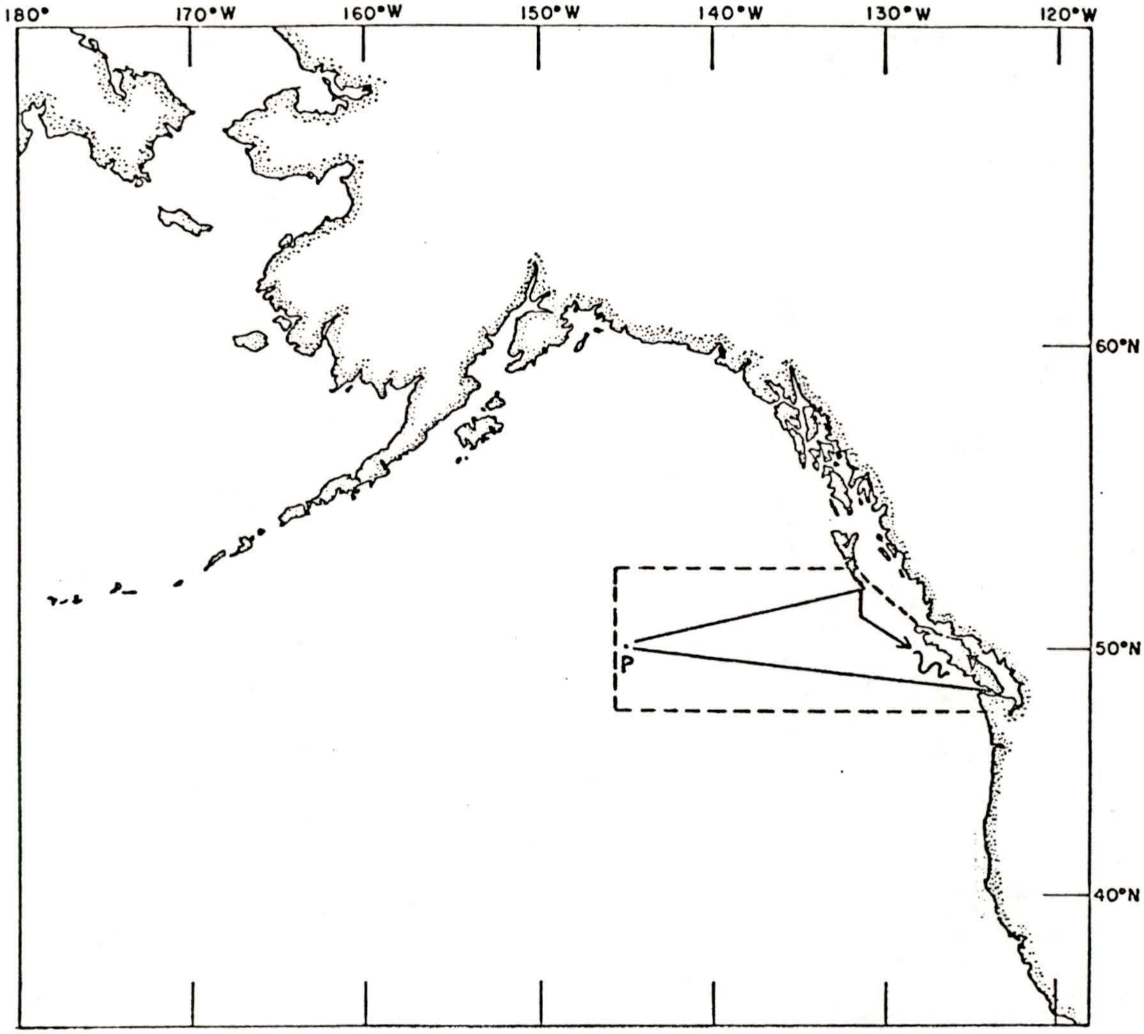

Figure 1: Map of western North America and part of the northeast Pacific ocean showing the study area outlined, with generalized transect route indicated. P is position of former weather ships, 145°W, 50°N. Curved section near coast of Vancouver Island (V) indicates area where routes varied from cruise to cruise.

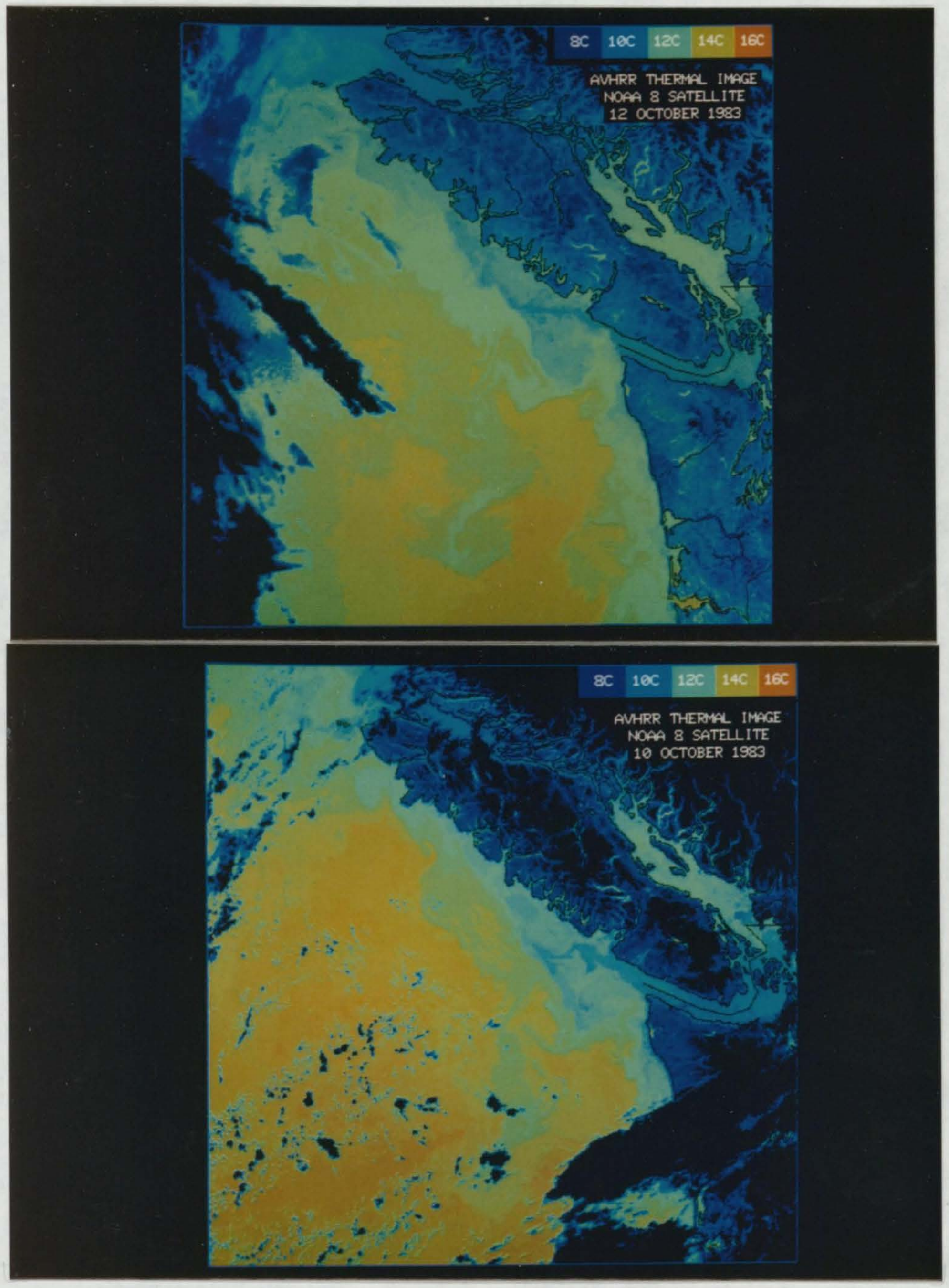

Figure 2: Satellite images of surface temperatures off the coast of Vancouver Island, October 1983. Note increase of temperature with distance offshore. Dark blue/black is cloud.

1.4 OBJECTIVES

Within the given limitations, specific objectives of this thesis were to:

1. discern possible distribution patterns of major seabird species groups;

2. determine what correlation (if any) exists between observed numbers of seabirds (by species groups) and the temperature of the sea surface;

3. determine what correlation (if any) exists between observed numbers of seabirds (by species group) and salinity;

4. determine what correlation (if any) exists between offshoreness, as represented by three areas (shelf, slope and pelagic waters) and the observed numbers in each species group;

5. determine existence of possible relationships between observed numbers of seabirds and (a) season and (b) weather; and

6. examine the effects of selected factors on the at-sea visibility distances for typical seabird species.

Following chapters detail the analysis methods; present the results; discuss those results in terms of possible errors, reliability, unsolved problems and comparison to other research and finish with recommendations.

1.4 OBJECTIVES

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[illegible]

1\. [illegible] distribution [illegible] [illegible]

2\. [illegible]

3\. [illegible] correlation [illegible]

4\. [illegible] correlation [illegible]

7\. [illegible]

5\. [illegible] examine [illegible] differences [illegible]

[illegible] analyses [illegible] resulting discussion [illegible] reliability, [illegible] problems, and [illegible] research and [illegible]

CHAPTER 2

METHODOLOGY

This chapter details the selection of variables (Section 2.1), methods of data collection (2.2), visibility tests (2.3), preparation of data for analysis (2.4) and data analysis procedures (2.5). Since all the seabird data are based on observation, visibility tests were undertaken to assess the likely accuracy of the data. Results of those tests also guided the subsetting of the main data base for chi-square and correlation analyses.

2.1 SELECTION OF VARIABLES

Researchers have suggested that patterns of seabird occurrences are probably linked to environmental factors: salinity, temperature (Salomonsen, 1965); combined salinity and temperature (Pocklington, 1979); season, distance to breeding site (Nettleship & Gaston, 1978); local upwelling and species associations (Porter,1981). A review of data collected by K. Vermeer (pers.comm.) during the first of a series of oceanographic cruises to Station P helped refine a seabird species list. That list was expanded to include

CHAPTER 2

METHODOLOGY

This chapter [illegible] details the [illegible] (Section 2.1), methods of data collection [illegible] tests (2.3), preparation of [illegible] for analysis [illegible] and data analysis [illegible] (2.5). Since [illegible] are based on observations, [illegible] to assess the [illegible] accuracy of the [illegible] of those [illegible] data [illegible] chi-square [illegible].

2.1 SELECTION OF VARIABLES

[illegible] occurrences [illegible] salinity, [illegible] and temperature [illegible] breeding [illegible] and [illegible] (Fisher, 1981) [illegible] [illegible] a few other variables which were thought to have a possible but unlikely link with seabirds (e.g. drift).

Subjective consideration was also given to ease of data collection, required instrumentation, probable information contribution and possible collection cost. The variables can be classified into three groups: first, those which record time, location and environmental conditions; second, the list of seabird species; and third, the peripherals (Table 1).

Table 1: Variables and their code equivalents for which data was collected during ten minute observation periods.

	VARIABLES	CODES
GROUP ONE		
	YEAR	Y
time	MONTH	M
	DAY	D
	HOUR (to 1/10 hour)	H
location	LATITUDE (to 1/100 degree)	LAT
	LONGITUDE (" " ")	LONG
environmental	SALINITY (to 1 part/100,000)	SAL
conditions	TEMPERATURE (to 1/100 degree)	TEMP
	DEPTH (to nearest meter)	DEPTH
	VISIBILITY (>300m=1, <300m=2)	VIS
	WIND (<15 knots=1, >15knots=2)	WIND
	PRECIPITATION (nil=1, some=2)	PREC
GROUP TWO		
	ARCTIC LOON	ARLO
species	BLACK-FOOTED ALBATROSS	BFAL
list	LAYSAN ALBATROSS	LAAL
	NORTHERN FULMAR	FULM
	SLENDER-BILLED SHEARWATER	SLSH
	SOOTY SHEARWATER	SOSH
	BULLER'S (N.Z.) SHEARWATER	NZSH
	FORK-TAILED STORM-PETREL	FTPE
	LEACH'S STORM-PETREL	LEPE
	MOTTLED (SCALED) PETREL	SCPE
	LONG-TAILED JAEGER	LTJA
	POMARINE JAEGER	POJA
	PARASITIC JAEGER	PAJA
	PHALAROPE SP.	PHAL
	GLAUCOUS-WINGED GULL	GWGU
	CALIFORNIA GULL	CAGU
	HERRING GULL	HEGU
	MEW GULL	MEGU
	BONAPARTE'S GULL	BOGU
	SABINE'S GULL	SAGU
	BLACK-LEGGED KITTIWAKE	BLKI
	COMMON MURRE	COMU
	MARBLED MURRELET	MAMU
	ANCIENT MURRELET	ANMU
	PIGEON GUILLEMOT	PIGU
	CASSIN'S AUKLET	CAAU
	RHINOCEROS AUKLET	RHAU
	TUFTED PUFFIN	TUPU
	TERN SP.	TERN

Table 1 continued: Variables with their code equivalents for which data was collected during ten minute observation periods.

	VARIABLES	CODES
GROUP TWO		
	CORMORANT SP.	CORM
	WATERFOWL SP.	WFOWL
species	SHOREBIRD SP.	SHORE
list	LOON SP.	LOON
	UNIDENTIFIED SMALL GULL	SGULL
	UNIDENTIFIED LARGE GULL	LGULL
	UNIDENTIFIED ALCID SP.	ALCID
	UNIDENTIFIED STORM-PETREL SP.	UPETR
	OTHER SHEARWATERS (not above)	OTSH
	OTHER BIRDS (none of above)	OBIRD
	TOTAL BIRDS	BIRD
GROUP THREE		
	DALL'S PORPOISE	DALLP
mammals	PACIFIC STRIPED PORPOISE	PACSP
	HARBOUR PORPOISE	HARBP
	NORTHERN FUR SEAL	FSEAL
	HARBOUR SEAL	HSEAL
	WHALE SP.	WHALE
	OTHER MARINE MAMMAL (not above)	OMAMM
drift	DRIFTING OBJECTS (logs,etc.)	DRIFT

2.2 DATA COLLECTION

The actual collection of data on the selected variables occurred in four subsections, separated primarily by logistical considerations:

1. transect routes (time and location)
2. collection of oceanographic data, and
3. collection of weather data.
4. collection of seabird observations,

2.2.1 Transect Routes

All transects started at Race Rocks (48°17'N, 123° 32'W) near Victoria, British Columbia and followed an almost straight line westward across a portion of the northeast Pacific Ocean to the position once held by Canadian weather ships at Ocean Weather Station Papa (50°N, 145°W). The return route was east and slightly north to just off Cape St. James at the south end of the Queen Charlotte Islands (52°N, 131° 10'W) then south to about 50°50'N, 131°W and from there southeast to the entrance of Juan De Fuca Strait and Victoria (Figure 3). Latitude and longitude data were recorded to the nearest 1/100 degree from the ships' navigational instruments and were assumed to be accurate to within one kilometer.

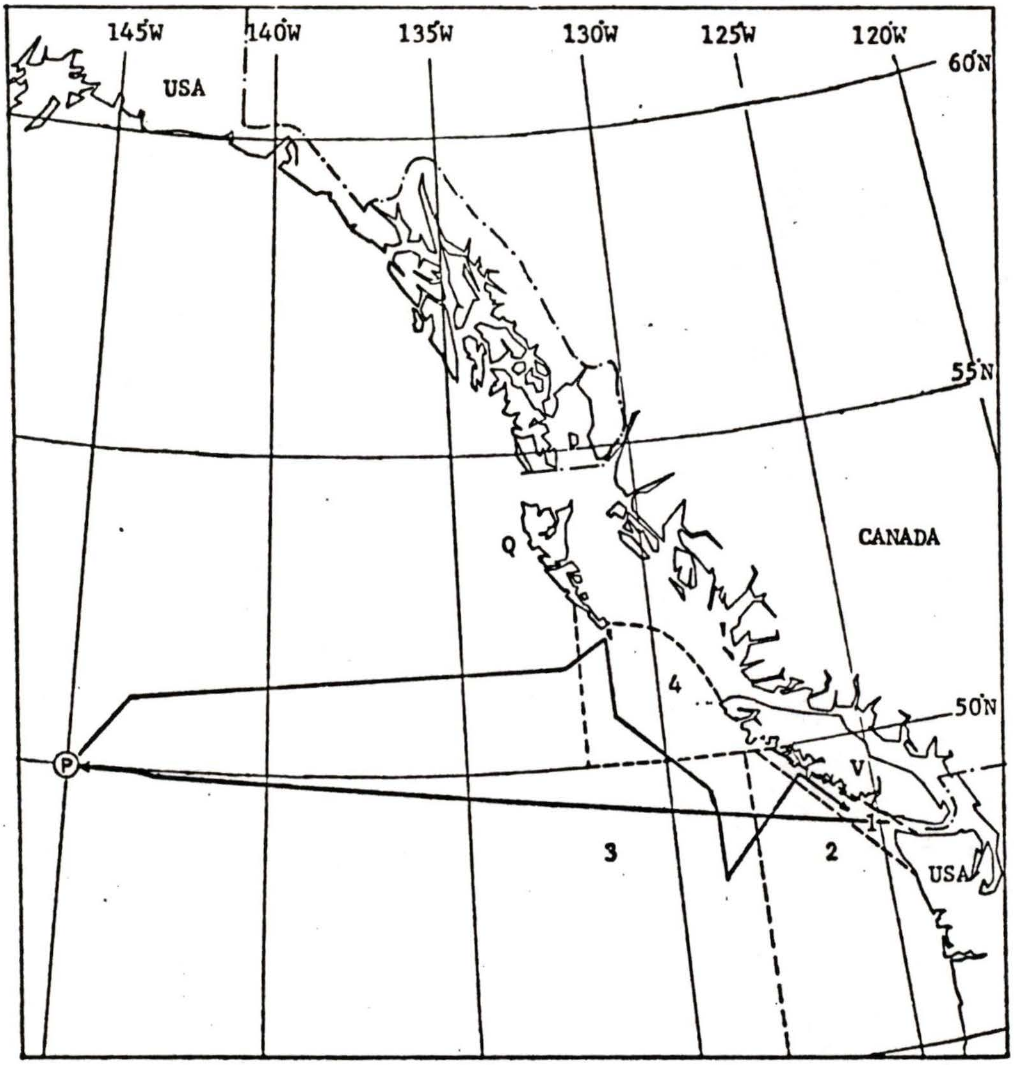

Figure 3: Route followed by CSS Parizeau May, 1982. Note Vancouver Island (V), Queen Charlotte Islands (Q) and Ocean Station Papa (P). Area 1 is over the shallow shelf off SW Vancouver Island. Areas 2 and 4, over deeper water (200-3000 meters) but within zone of coastal events (upwelling, foraging birds from breeding sites), are combined as area 2 for analysis. Area 3 is deep pelagic water beyond coastal influence.

2.2.2 Collection Of Oceanographic Data

All oceanographic data were collected by the ships' scientific staff. The onboard instrument package included a Plessey model 6600 thermosalinograph which continuously recorded salinity and temperature of the surface water layer sampled via a seawater loop taken from just below the ocean surface. Data from this instrument were also recorded in the bird log at the beginning and end of each birdwatch (a nominal two hour period) and used as keys to facilitate the complete data merging step conducted later.

2.2.3 Collection Of Weather Data

Weather data were collected for visibility, wind and precipitation. Each variable was given a value of 1 or 2 (Table 2). Visibility was estimated with the use of a Suunto clinometer. A mark was placed on the frame of a window so that a sight line passing it, from a distance of one meter, intersected sea level at 300m. The 300m threshold between visibility classes represents the approximate limit at which small alcids on the sea surface could be seen under good conditions (section 2.3). Wind speed was provided by the ship's officer on watch or read by the author from the ship's anemometer. Fifteen knots was

2.2.2 Collection Of Oceanographic Data

[illegible] facilitate the [illegible]

2.2.3 Collection Of Weather Data

[illegible]

chosen as the division point for wind classes because that is the speed above which whitecaps become numerous and interfere with the detection of seabirds on the water. Changes in visibility in relation to wind (Figure 30) appear to support this choice. Presence or absence of precipitation was noted although its potential effects were unknown. Raw data was coded to categorical values so that conditions of good weather were numerically low. The resultant spectrum of values ranged from 111 (no fog, no or slight wind, no rain) to 222 (fog, high wind, rain). It was anticipated that these discrete classes would prove useful in chi-square analysis.

Table 2: Assignment of values for weather variables, visibility, wind and precipitation, based on observed conditions.

VISIBILITY		WIND (in knots)		PRECIPITATION	
>250m	<250m	<15	>15	absent	present
1	2	1	2	1	2

2.2.4 Collection Of Seabird Observation Data

Observed seabirds were identified to species level, counted and recorded using the techniques of Nettleship

(1976) and Brown et al (1975), with the noted modifications.

Observations were made with the unaided eye although binoculars were at hand in case of difficult identifications. All identifications were checked at sea against commonly used field guides (Peterson, 1961 and Robbins, Bruun, Zim, & Singer, 1966). The arc of observation extended from the bow through 90 degrees to whichever side had the least sun glare at the time. It was assumed that no bias was introduced by this since the number of observations per side were near equal within each area. The observer was usually positioned in a forward corner of the bridge or outside on the top deck above the bridge (Figure 4).

Data from contiguous ten minute observation periods were recorded while the ship was cruising at a nominal speed of 10-11 knots. The bow to beam quadrant was scanned continuously out to an estimated 300m perpendicular to the ship's course. Therefore as the vessel advanced, a 300m wide transect with length equal to distance travelled in ten minutes was surveyed (Figure 5). A string of ten minute observation periods was recorded as the ship advanced from one oceanographic sampling station to

(1976) and [illegible] al. (1977) [illegible] noted [illegible].

[illegible] with the [illegible] d [illegible] although [illegible] were at hand [illegible] identification [illegible] against [illegible] used for [illegible] (Harrison, 19[illegible]; Robbins, [illegible] Zim, [illegible] Singer, [illegible]). [illegible] observation [illegible] unidentified [illegible] number of [illegible] area. [illegible] of the bridge [illegible] (Fig. [illegible]).

[illegible] were recorded [illegible] speed of 10 [illegible] continual [illegible] ships' course [illegible] side [illegible] A [illegible] adv[illegible] another, usually eight or ten periods per string. Usually about six hours of observation (36 observation periods) were possible every day.

While the ship was stopped on station, observations ceased and instrument readings were checked. When the ship resumed its course the observations were also resumed. This routine helped combat eye-fatigue and boredom. Farther offshore, where distances between stations took over two hours to traverse, a break was taken about every two hours depending on circumstances. At the beginning and end of each series of observations, time, position and weather data were noted from the ship's instruments.

In summary, seabird observations were recorded for a series of transect survey sections, each the result of a ten minute watch covering a strip 300m wide and 3087m long (.926km^2), assuming a ship speed of 10 knots (18.5 km/h). These watches are similar to the units of effort used by Guzman and Myres (1983). In a normal day 30 to 40 such transect sections were surveyed. Useable data were obtained from 1850 ten minute watches out of the 66 days spent at sea on six voyages.

[illegible] activity [illegible] ... [illegible] were possible every day.

While the ship was [illegible] ceased [illegible] resumed [illegible] the [illegible]. This [illegible]. Farther [illegible] over two hours [illegible] two hours, depending [illegible] end [illegible] observations [illegible] weather [illegible] from the ship's [illegible].

In summary, seaboard observations were [illegible] series of [illegible] each [illegible] ten minutes [illegible] [illegible] These [illegible] transect [illegible] obtained [illegible] [illegible].

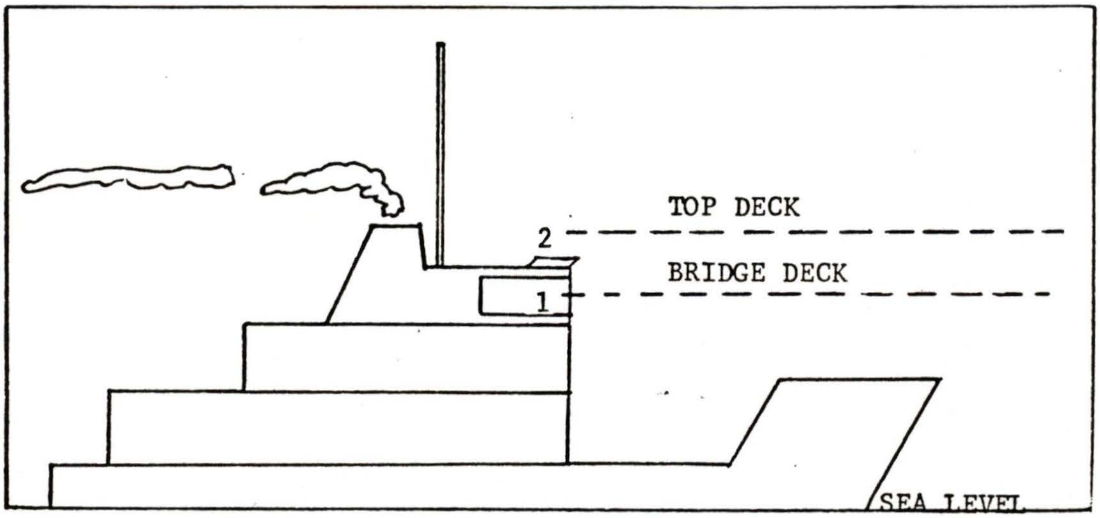

Figure 4: Normal positions of observer for birdwatches on board oceanogrphic ships during trips to Station P.

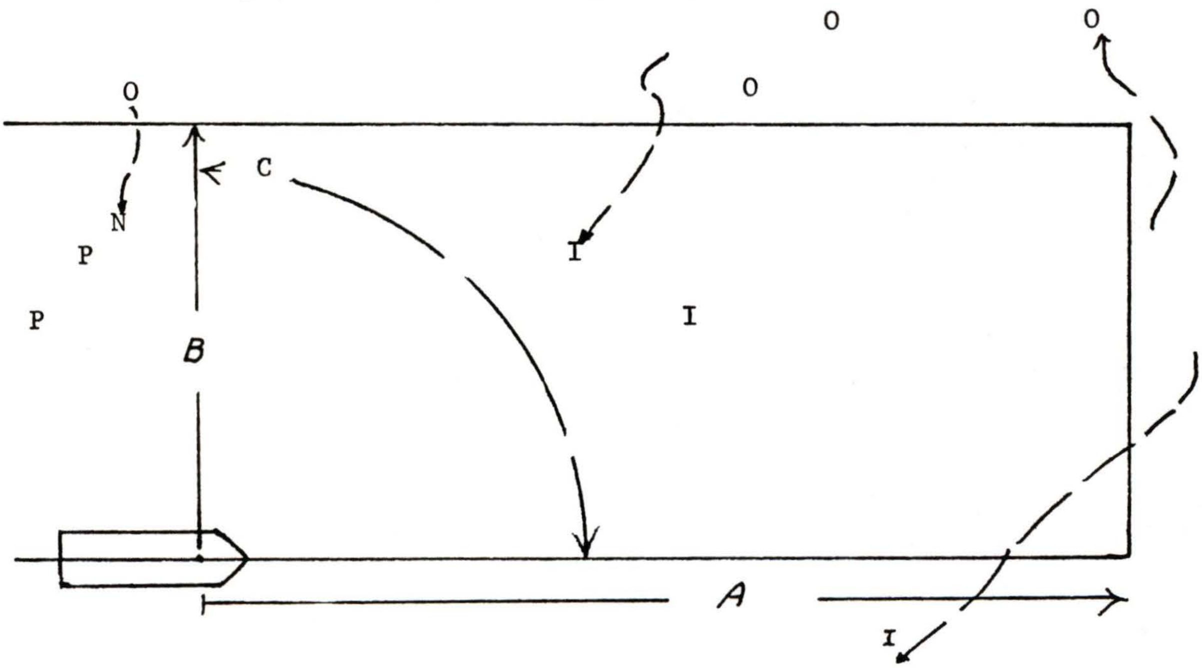

Figure 5: Sketch of area surveyed during a 10 minute period. Transect width B = 250 meters, A = distance travelled in 10 minute period, O = bird outside of transect zone and not counted, I = bird counted in zone both stationary and flying, P = bird counted in previous period, N = bird not counted (outside during previous period and flew into current zone behind arc of observation C).

2.3 VISIBILITY EXPERIMENTS

As an aid to selecting an appropriate value for the transect width and to examine the effects of various wind conditions, observer postions and differences in seabird size and colour on visibility, a simple experiment was conducted. Balloons simulating seabirds of two sizes, 10 centimeters (Cassin's auklet or marbled murrelet) and 16 cm. (tufted puffin or medium to large gull), and two gray tones, light (mature gulls) and dark (shearwaters, immature gulls and most alcids) were dropped overboard. Each balloon was water ballasted to one third its volume to minimize wind induced drift.

The balloons were placed overboard and observed from two different deck heights. Times measured from the time they passed astern of the observer until they could no longer be seen were recorded to the nearest tenth second. Referring to Figure 6 a and b, time was started at position P1 and stopped when the observer could no longer see the object, at P2. Time (T) and speed (S) of the ship were then used to calculate the distance between P1 and P2. That procedure was repeated for several combinations of observer height, balloon size and balloon colour under three sets of wind conditions. Similar tests were made in May 1982 using empty cans.

2.3 VISIBILITY EXPERIMENTS

As an [illegible] selection [illegible] [illegible] [illegible] [illegible] [illegible], [illegible] from [illegible] [illegible] visible [illegible] balloons [illegible] cm [illegible] [illegible] light [illegible] gulls and [illegible] [illegible] [illegible] [illegible] [illegible].

The [illegible] were placed [illegible] [illegible] different [illegible] heights. Time [illegible] [illegible] [illegible] [illegible] recorded [illegible] [illegible] [illegible] Figure [illegible] [illegible] [illegible] objects. [illegible] Time (t) and speed (s) [illegible] [illegible] used to [illegible] [illegible] that procedure was [illegible] [illegible] observer height, balloon [illegible] [illegible] three [illegible] [illegible] May 1982 [illegible].

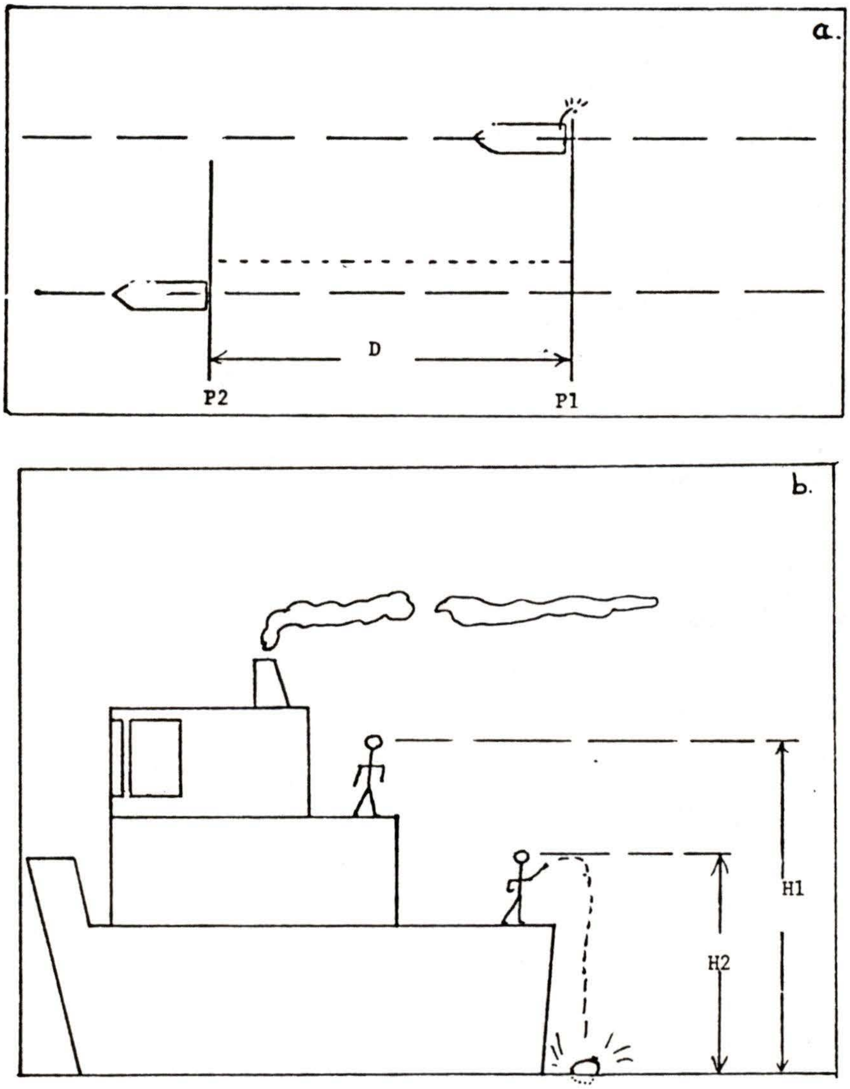

Figure 6a, b: With ship at position P1, observer (X) on bridge deck at height H1, a balloon was placed in the water, time was started. At P2, when observer X could no longer see the balloon time was stopped. The routine was repeated with the observer on the main (lowest) deck at height H2. Time and ship speed were used to calculate distance.

Results (Tables 3 & 4 below, and Figures 27 to 30, Appendix) show that changes in any of the four factors could alter the visibility distance of seabirds on the water. Although the results are inconclusive they suggest that during winds below 15 knots, visibility particularly for small birds, is greater than during winds over 15 knots (Figure 27). A more complete study of this subject may show that the threshold occurs at even lower speeds. The effect of gray tone confirms the intuitive belief that light objects are more visible.

Because wind is the only one of these factors for which data was recorded during at sea observations and because it seems desirable to attempt to limit one source of variation, data were sorted by wind into two groups, below and above 15 knots. The low wind data (1413 of 1851 observations) were used in subsequent correlation analysis.

The average visibility distances are optimistic because they are based on known targets disappearing astern rather than spotting unknown targets ahead and timing the ships' approach to them. The range of distances (212-519m) does provide some justification for the choice of 300m as the transect width, although small dark birds are probably underestimated, especially during winds above 15 knots. In all but one case the higher observer position gives better visibility and thus supports the use of the bridge deck observer position.

In summary the tests results were useful as a guide in the following choices during data collection and data preparation: observer position (bridge), transect width (300m) and the use of wind classes divided at 15 knots.

Table 3: Mean distances (meters) at which targets (cans) disappeared from sight during several different combinations of observer height, target size and target gray tone tabulated with number of observations (n) and standard deviation (s). May/82.

OBSERVER POSITION	OBJECT SIZE and COLOUR		
	LARGE Diam.=10.5cm Leng.=17.5cm		SMALL D=7.5 cm L=10 cm
	DARK	LIGHT	DARK (only)
TOP DECK (H1) 9 meters	D=254m s=44.4 n=3	D=330m s=32.7 n=3	D=155m s=20.5 n=3
BOTTOM DECK (H2) 3.5 meters	D=177 s=4.2 n=3	D=282 s=42.7 n=3	D=123 s=13.1 n=3

Table 4: Mean distances (meters) at which targets (balloons) disappeared from sight during several different combinations of wind, observer height, target size and target gray tone tabulated with number of observations (n) and standard deviation (s). May 1985.

		COLOUR LIGHT		DARK	
		SIZE LARGE d=16 cm	SMALL d=10 cm	LARGE d=16 cm	SMALL d=10 cm
OBSERVER HEIGHT	WIND SPEED				
9 meters	5	no data	D=519 S=45 N=10	no data	no data
	10	D=437 m S=52 N=6	D=347 m S=7 N=4	nd	D=212 S=13 N=7
	20	D=373 S=37 N=8	nd	D=271 S=41 N=4	nd
3.5 meters	5	nd	D=434 S=76 n=9	nd	nd
	10	D=347 S=40 N=6	D=304 S=18 N=4	nd	nd
	20	nd	nd	nd	nd

2.4 PREPARATION OF DATA FOR ANALYSIS

In preparation for analysis the raw data were first inspected for obvious trends and patterns. Suspect data were checked against field notes for errors, corrected if possible, or discarded. Inspection also revealed that the data on some variables were inadequate for further work. Those variables were removed from the data base. The remaining data were then prepared for analysis by the preliminary procedures to:

1. Merge seabird observation data with oceanographic data.
2. Perform frequency analysis on all species.
3. Define species groups.
4. Define abundance classes.
5. Define trips.
6. Define survey areas.

2.4.1 Data Merging

Seabird observation data and oceanographic data were merged manually. Latitude, longitude, salinity and temperature were taken from the oceanographic log and matched to data in the seabird records from each trip by comparing dates and times and key latitudes and longitudes noted at the beginning and end of each birdwatch. Subsequent sorting and subsetting were done by computer.

During this stage a small number of records were

discarded because no matching temperature and salinity data were present in the oceanographic log. Data from August 1981 (Vermeer, pers. comm.) and September 1982, although made available by the Canadian Wildlife Service, could not be incorporated because of incompatibilites in collection methodology.

2.4.2 Frequency Analysis

Frequency analysis was performed on all seabird species using the SAS routine PROC FREQ (SAS Institute, 1982). The analysis indicated the frequency with which counts of 0,1,2,...n had been recorded for each species, and showed that data on several species was too sparse for meaningful analysis. For example, during 267 ten-minute observation periods in October 1981, only 8 Leach's storm-petrels were recorded, six single occurrences and one pair. The other storm-petrel regularly encountered in the study area, the fork-tailed storm-petrel occurred as follows: ten ones, five twos, one three, two fours, one five and one seven (Table 5). Similarly low numbers observed for the alcids, albatrosses and gulls necessitated the combinations of some species into species groups as defined in section 2.4.3.

Table 5: Example of results from frequency analysis of seabird observations for trip 1, October 1981.

SPECIES	OBS'D NUMBER	FREQUENCY
sooty shearwater	0	222
	1	20
	2	5
	3	7
	4	1
	6	3
	7	2
	8	1
	11	2
	16	1
	22	1
	25	1
	38	1
black-footed albatross	0	216
	1	42
	2	9
Laysan albatross	0	246
	1	19
	2	2
Leach's storm-petrel	0	260
	1	6
	2	1
fork-tailed storm-petrel	0	247
	1	10
	2	5
	3	1
	4	2
	5	1
	7	1

2.4.3 Species Groups Definition

Inspection of results from the frequency analysis led to the formation of seven species groups: SOOTY SHEARWATERS, LARGE GULLS, STORM-PETRELS, ALCIDS, ALBATROSSES, BLACK-LEGGED KITTIWAKES and BIRDS. Groups were formed principally on the basis of behaviour at sea. Alcids, for example, typically swim on the surface and dive in pursuit of prey in contrast to the storm-petrels who spend a much larger proportion of time in the air or feeding at the surface. These behaviour patterns are of significance when one attempts to assess the potential seabird mortality in pelagic drift nets or the impact of an oil spill.

Sooty shearwaters (SOSH) were retained as a single species group since they far outnumbered all other shearwaters in the observations. Black-legged kittiwakes (BLKI) could not be logically combined with any other species although they most resemble gulls in behaviour. Fork-tailed storm-petrel (FTPE) and Leach's storm-petrel (LEPE) were combined in PETRELS. The ALBATROSS group was a combination of Laysan (LAAL) and black-footed albatross (BFAL). Common murre (COMU), marbled murrelet (MAMU), Cassin's auklet (CAAU), rhinoceros auklet (RHAU), tufted puffin (TUPU) and ancient murrelet (ANMU) were combined to form the ALCIDS group. Herring gulls (HEGU), glaucous-winged gulls (GWGU) and California gulls (CAGU) as well as unidentified large gulls (LGULL, Table 1) were grouped together as LGULLS. The group BIRD represents the total number of observed birds.

2.4.4 Definition Of Abundance Classes

After inspection of frequency analysis results for the species groups above, five abundance classes were formed within each group. These classes were created to provide a manageable number of categories for subsequent use during chi-square analysis in which the existence of relationships between seabirds and (a) season and (b) weather were tested.

Class 0 contained observations of zero birds; class 1, one bird; class 2, two birds; class 3, three to five birds and class 4, observations of six or more birds. Table 6 shows construction of abundance classes based on frequency of count occurrences. Zero counts were placed in a separate class because they far outnumbered other counts which ranged up to a single estimate of 10000. Other counts were divided as equally as possible into the other four categories. An attempt was made to define the categories so that each would contain at least five observations per species group for chi-square analysis.

Table 6: Abundance classes with numbers of observations in each class, by species group all trips combined. N=1850.

DEFINITIONS	BIRD	SOSH	PETRELS	GULLS	ALCIDS	ALBAT'S	BLKI
count=abun. class	(numbers of observations in each class)						
zero = 0	931	1631	1676	1626	1585	1666	1651
1 = 1	315	96	99	91	116	126	115
2 = 2	174	31	41	42	57	39	36
3-5 = 3	212	31	23	57	38	14	33
6+ = 4	218	61	11	34	54	5	15

2.4.5 Definition Of Trip And Season

The categories trip and season were derived from the variables year and month as shown in Table 7. The trip made in October 1981 was trip 1 with subsequent trips numbered in order by date. Surveys made in January, March, May and October were respectively classed as having occurred in season 1, 2, 3 or 4 (winter, spring, early summer and fall). There were no midsummer trips.

from tabulation [illegible] were [illegible] the

latter [illegible] that [illegible]

of [illegible] were [illegible] group [illegible] chi-square [illegible]

Table 6. [illegible] abundance [illegible] classes [illegible] trip [illegible]

DEFINITIONS	TRAP	PUSH	[illegible]	[illegible]	[illegible]
(abundance class)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
"Zero" = 0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] = 1	[illegible]	30	90	8	10
[illegible] = 2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] = 3	[illegible]	31	[illegible]	[illegible]	[illegible]
[illegible] = 4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

2.4.5 Definition Of Trip And Season

The [illegible]

variables [illegible] year [illegible] as [illegible]

made in [illegible]

numbered in [illegible] date. [illegible]

May and October [illegible]

occurred in [illegible]

summer [illegible]

Table 7: Derivation of trip and season from year and month.

TRIP	YEAR	MONTH	DATE	SEASON
1	1981	October	19-28	fall
2	1982	January	18-29	winter
3	1982	March	15-26	early spring
4	1982	May	4-13	early summer
5	1983	March	17-28	early spring
6	1983	October	6-17	fall

2.4.6 Definition of survey areas

The complete study area included regions of shallow water over the narrow continental shelf off the southwest coast of Vancouver Island, a transition zone from shelf to abyssal plain and the deep water pelagic area where depth averaged 4000 meters. A small computer program was written to assign area codes using latitude and longitude data on a simple basis.

Area 1 contains the narrow band of nearshore water lying over the shelf between Vancouver Island's southwest coast and a staight line approximating the 200m isobath extending from near Cape Cook (50°N, 128°W) southeasterly to latitude 48°N, longitude 125°30'W. Area 2 lies south of latitude 50°N and east of longitude 128°W but outside of area one. It provides data from transects over the transition zone crossing the continental slope. Area 3 provides data from the pelagic zone of deep water west of the other areas. Area 4 is north of latitude 50°N and east of longitude 132°W and provides data for the portion of transects passing through a northerly section of the transition zone between shelf and deep water near Cape St. James and Triangle Island, both major seabird colony sites. Areas 4 and 2 were later merged as area 2 because they are both samples of the transition zone. Table 8 shows conditions used in defining the four survey areas.

Table 8: Derivation of areas with area descriptions.

CALCULATION	AREA	DESCRIPTION
if(long<=128 00 and long>0 and (lat/100<=(.477*long/100)-10.846)) and ((lat/100>=(.84*long/100)-57.42))) then area =	1	contains transects over shallow nearshore shelf between Vancouver I. and a line from 50°N, 128°W SE to 48°N, 125°30'W
if (lat <= 50 00 and long <= 128 00 and area not equal 1) then area =	2	contains transects off W coast of Vancouver I. between area 1 and foot of contintental shelf slope
if ((long > 128 00 and lat <= 50 00) or (long>132 00 and lat >5)) then area =	3	contains transects through distant pelagic waters, outside of areas 1,2 and 4
if (lat > 50 00 and long < 132 00) then area=	4 *	contains transects from near Cape St. James, QCI, to west of N Vancouver I.

* area 4 was later merged with area 2.

2.5 DATA ANALYSIS

Almost all the analyses of the data were computed using packaged procedures within SAS (Statistical Analysis System). Exceptions were calculated or plotted by hand. The particular procedures used included SORT, FREQ, CORR, GCHART and GPLOT (SAS Institute Inc., 1982).

The SORT procedure was used to sort the data by area, trip and sometimes wind prior to other analyses. The FREQ program was used for frequency analysis of the occurrences of every value of selected variables (useful in setting class limits), for descriptive statistics and for chi-square analysis.

Procedures GCHART and GPLOT were used to create graphic representations of the data for visualization of relationships between variables. Three dimensional block diagrams (Figures 7-12) were created with variables longitude, latitude and mean counts of species groups plotted on axes x,y, and z respectively, repeated for each trip. Similarly plotted block diagrams depict mean species counts in temperature/salinity cells (Figures 19-24).

Vertical bar graphs (Figures 13-18) indicate relationships between the major species groups and distance

2.5 DATA ANALYSIS

[illegible]

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[illegible]

offhore during each of the six trips. repeated for each species group sorted by area and trip.

The CORR procedure produced correlation statistics for the selected species groups and environmental factors salinity, temperature and area. The problems were defined in the style of Norcliffe (1982). Because the data do not have a bivariate normal distribution, and cannot be easily transformed, Spearman's correlation was chosen rather than Pearson's r.

The test was repeated for each trip, excluded two anomalously large flocks (9000+ birds) and only considered data collected while wind was less than 15 knots to minimize some of the variation in visibility (and hence observed numbers). Sample sizes range from 99 to 545, abundance classes from 0 to 4, salinity from 28.00 to 32.50 parts/thousand, temperature from 6.00 to 14.80 degrees Celsius. Area values are 1, 2 or 3.

In summary, these analyses attempted to answer the questions of the introduction by computing Spearman correlations (to indicate correlations between birds and salinity, temperature and distance offshore); chi-square analyses (for detection of relationships between birds and [illegible] each of [illegible] bounded [illegible] between [illegible]

The [illegible] procedure [illegible] stations for the selected [illegible] salinity, [illegible] and [illegible] the [illegible] have a [illegible] distribution [illegible] and [illegible] transformed [illegible] station was [illegible]

The [illegible] was [illegible] stations, [illegible] and [illegible] minimize [illegible] the variation in [illegible] abundance [illegible] use [illegible]

[illegible] summary, [illegible] attempted [illegible] by [illegible] correlations between [illegible] season or weather) and by graphic plots (to reveal spatial and temporal patterns) while area, trip and weather effects were controlled.

CHAPTER 3

RESULTS

The questions posed originally in the introductory statement of objectives asked:

(a) are there patterns in the occurrences of birds at sea; if so what controls the shape of these patterns?

(b) is there a correlation between salinity and the occurrence of birds at sea, and if so what is the nature and significance of that correlation?

(c) is there likewise a correlation between temperature and birds?

(d) how are birds correlated with distance offshore?

Two approaches to these problems were used: (1) graphical, and (2) statistical.

3.1 GRAPHICAL ANALYSIS FOR PATTERN DETECTION

The data were sorted primarily by trip and area so that those factors could be held constant while the effects of environmental factors such as salinity and temperature were examined. First inspections of the data led to the use of three dimensional block charts (Figures 7-12) to portray the latitudinal and longitudinal distribution of the mean number counted in each species group during observation periods.

A trend towards fewer birds as distance offshore increases is most apparent along the row for the 49th parallel of latitude visible in Figures 8, 9, 10, 12 and less obviously in 7. When counts of species groups were grouped by area within trip (Figures 13-18) it became apparent that alcids tended to be most numerous in the shelf zone closest to shore.

In an attempt to reveal possible bird occurrence patterns in relation to salinity and temperature a second series of block charts was created (Figures 19-24). From these, no recurrent pattern nor trend is apparent although certain species do exhibit greatest abundance at unique salinity / temperature / date intersections, for example, alcids at sal 3150 / temp 10 / October 81 (Figure 19).

The SAS procedure PROC GCHART was used to create pie charts for each combination of trip and area (Figure 25). Pie sections represent the portion of the mean total of all birds contributed by each species group. The inner circles' diameters are proportional to the logs of the sum of species group means summed for each case and are useful for comparing those sums among the 18 cases. For example, the average total number of birds observed in area 3 in all cases is smaller than in area 1, all cases.

3.2 STATISTICAL ANALYSES

Although patterns in the data were apparent in some figures the significance of relationships and correlations could not be established by that treatment of the data alone. In the following sections each problem is stated and the appropriate test is described along with the variables involved. Results from analysis of the first three problems are summarized in Table 9.

3.2.1 Correlation of birds with offshoreness

THE PROBLEM: Is there any correlation between observed numbers of birds and distance offshore (offshoreness)? Because the data were sparse, distance offshore was classified into only three area categories; (1)shelf, (2)transition and (3)pelagic/deep water zones. Are birds more numerous in one of these areas than another? Is this correlation consistent for all times of the year or

unique to one season? An attempt to answer this multipart question is made by examining, trip by trip, the Spearman's correlation of each species group with degree of offshoreness as indicated by area.

THE NULL HYPOTHESIS, H0: the number of birds (in a species group) counted per unit effort (a ten minute period of observation) is not correlated with degree of offshoreness (i.e. correlation=0).

THE RESEARCH HYPOTHESIS, H1: the number of birds (in a species group) counted per unit effort is correlated with degree of offshoreness. The test is two-tailed.

LEVEL OF SIGNIFICANCE, a=.01

DEGREES OF FREEDOM = N-2 (e.g. 265 for Trip 1)

Spearman's rank correlation coefficient is computed for each species group, by trip, using count values recorded for each species group (VARIABLE 1) and area value (VARIABLE 2). Data are limited to observations made when wind was less than 15 knots and exclude counts greater than 2000. For example, during trip 1, number of observations (N) is 267, and for species group SOSH the cross-tabulation with AREA is approximated in the matrix below, using abundance classes for simplicity.

AREA	CLS 0 0 birds	CLS 1 1 bird	CLS 2 2 birds	CLS 3 3-5 birds	CLS 4 6+ birds
1	32	6	1	5	3
2	40	3	0	2	9
3	151	11	4	1	0

[illegible] An [illegible]

question [illegible]

[illegible]

[illegible]

[illegible] HYPOTHESIS [illegible]

[illegible]

THE [illegible]

LEVEL OF SIGNIFICANCE, [illegible]

DEGREES OF FREEDOM = N [illegible]

[illegible]

for each [illegible]

recorded [illegible]

[illegible]

[illegible]

[illegible]

[illegible] ARPA [illegible]

abundance classes [illegible]

[illegible]

In this procedure, every observation is ranked on both variables and the difference between rankings used in the calculation of the coefficient of correlation, Rs (Norcliffe, 1982). Rs is then used to calculate a t-value, which in turn is compared to a tabulated t-value for N-2 degrees of freedom, significance level=.01. When calculated t is greater, the null hypothesis is rejected and the alternative, H1, accepted.

In the case of SOSH, for example, Rs=-.23, t=3.847, exceeding tabulated t, therefore null hypothesis is rejected, H1 accepted. The test supports the conclusion that observed counts of SOSH are negatively correlated with area in October 1981. Since areas were ranked by distance offshore then the conclusion that SOSH are also negatively correlated with distance offshore is supported.

If results from trip 5 (March 1983) are discounted, because no area 1 data were collected then (Figure 16), a general trend is apparent in the correlations of observed numbers of birds with distance offshore (Table 9). For all birds together (BIRD), combined alcids (ALCID), and sooty shearwaters (SOSH) observed numbers decrease as distance offshore increases. Large gulls show the same trend except during October 1981. However, because area has only three [illegible] de, [illegible] data [illegible] there [illegible] for [illegible] the [illegible] of [illegible], [illegible] (1987) [illegible] is [illegible] [illegible] degrees [illegible] [illegible] 01. [illegible] [illegible] and the alternative, H[illegible], accepted.

In the case of (1986) for [illegible], [illegible] exceeding [illegible] indicated [illegible] H[illegible] accepted [illegible] test [illegible] that observed [illegible] of SSC? [illegible] area in October 1986 [illegible] were ranked [illegible] of [illegible] the conclusion that [illegible] correlated with distance [illegible]

In [illegible] (1987) [illegible], because [illegible] data [illegible] collected [illegible] general trend [illegible] in [illegible] observed numbers of [illegible] Table [illegible] blue [illegible] together [illegible] shorebirds [illegible] [illegible] during October 1987 [illegible] possible values a large number of tied rankings, though undesirable, is unavoidable. In consequence, the resultant correlations between species and distance offshore (represented by area) are viewed with caution.

3.2.2 Correlation of birds with salinity

NULL HYPOTHESIS, H0: average number of birds (by species group) counted per unit effort is not correlated with the level of salinity of the sea surface.

RESEARCH HYPOTHESIS, H1: average number of birds (by species group) counted per unit effort is correlated with level of salinity. Test is two-tailed.

LEVEL OF SIGNIFICANCE, a=.01

Correlation is tested between salinity (VARIABLE 1) and each species group (VARIABLE 2), by trip using Spearman's rank correlation. The number of observations per trip range from 99 to 545. Results (Table 9) show a significant negative correlation between total birds (BIRD) and salinity except during trip 5. Alcids show a similar significant negative correlation with salinity except on trip 5.

3.2.3 Correlation of birds with temperature.

NULL HYPOTHESIS, H0: number of observed birds (by species group) per unit effort has no correlation with temperature of sea surface.

[illegible] values [illegible] each
understanding [illegible]
correlation [illegible] between [illegible]
(represented by [illegible]) are [illegible].

3.2.2 Correlation of birds with salinity

NULL HYPOTHESIS: [illegible] species group [illegible] from the level of salinity [illegible].

ALTERNATE HYPOTHESIS: [illegible] species group [illegible] level of salinity [illegible].

LEVEL OF SIGNIFICANCE, α = .05

Correlation [illegible] between salinity [illegible] and each [illegible] group (VARIABLES [illegible]) [illegible] Spearman's rank [illegible] per trip [illegible] from [illegible] significant [illegible] and salinity except during trip [illegible] significant [illegible] with salinity [illegible] trip [illegible].

3.2.3 Correlation of birds with temperature.

NULL HYPOTHESIS: [illegible] species group [illegible] with temperature [illegible].

RESEARCH HYPOTHESIS, H1: number of birds (by species group) per unit effort is correlated with temperature of the sea surface. The test is two-tailed.

SIGNIFICANCE LEVEL, a=.01

Correlation is tested between temperature (VARIABLE 1) and counts of birds in each species group (VARIABLE 2), by trip, using Spearman's rank correlation in a manner similar to that noted in section 3.2.1. Results (Table 9) show a consistently significant negative correlation between observed numbers of sooty shearwaters (SOSH) and temperature throughout all trips, except #5 when there were no data. Observed numbers of black-legged kittiwakes are positively correlated with temperature for trips in October 1981, January 1982, March 1982 and March 1983.

Chi-square analyses were performed on the data in an attempt to assess the relationships of seabirds' presence to weather and season, two nominal variables. These tasks are formulated in the style of Norcliffe (1982) as two separate problems below.

3.2.4 Species group to season relationship

NULL HYPOTHESIS, H0: within each species group, the presence/absence of birds is unrelated to season.

RESEARCH HYPOTHESIS, H1: within each species group,

the presence/absence of birds is significantly related to season.

TEST: Chi-square, degrees of freedom=3

SIGNIFICANCE LEVEL: a=.01

There are two categories for bird presence (yes or no) and four seasons (winter, early spring, early summer and fall). Results (Table 10) indicate significant relationships between season and the presence/absence of birds for all species groups.

3.2.5 Species group to weather relationship

NULL HYPOTHESIS, H0: within each species group there is no relationship between the presence or absence of birds and weather.

RESEARCH HYPOTHESIS, H1: within each species group the presence or absence of birds is related to weather.

TEST: Chi-square, degrees of freedom=3

SIGNIFICANCE LEVEL: a=.01

There are two categories for presence of birds (yes or no) and four categories defined for weather. Referring to Table 2, Methods, the four weather classes are: A (Vis1, Wind1, Prec1); B (V1,W1,P2); C (V1,W2,P1) and D (V1,W2,P2 and all V2 cases). Results (Table 10) indicate a significant relationship between weather and the presence of birds for all species groups except storm petrels.

Spearman rank correlation coefficients (Table 9) indicate more clearly the nature and strength of correlations of birds with each of the environmental factors salinity and temperature, and areas ranked by degree of offshoreness. For example, a weak to moderate negative correlation, significant at the .01 probability level between alcids and salinity is constantly present except during trip five (March 1983) when area 1 (the nearshore shelf) was not sampled. On the other hand, temperature exhibits a significant weak to moderate positive correlation with kittiwakes, except for trip 6.

Results of analysis for correlation with areas of nearshore shelf, contintental slope and pelagic waters (area numbers 1,2,3, respectively) suggest, a highly significant, weak to moderately strong consistently negative correlation between total birds and distance offshore (Table 9). In other words, there are more birds closer to the coast.

Table 9: Spearman rank correlation coefficients (Rs) of species-groups on salinity, temperature and area, by trip. Data base excludes two counts greater than 2000 and is limited to weather conditions when wind was less than 15 knots (1413 observations out of 1851). @ signifies a total lack of observations of a species from the study area, no meaningful correlation possible.

TRIP 1, OCT/81, PROB>|R| under HO:RHO=0, N=267

ENV'L FACTOR		SOSH	ALBAT	ALCID	SPETR	LGULL	BLKI	BIRD
SALINITY	Rs	-.23	+.11	-.34	+.10	-.12	-.06	-.23
	prob.	.0001	.0779	.0001	.1155	.0501	.2932	.0002
	signif	**		**				**
TEMP	Rs	+.16	+.03	-.03	-.05	+.09	+.23	+.13
	prob.	.0087	.6292	.6656	.4608	.1459	.0002	.0285
	signif	*					**	
AREA	Rs	-.27	+.11	-.39	+.14	-.04	-.07	-.23
	prob	.0001	.0652	.0001	.0253	.5175	.2610	.0002
	signif	**		**				**

TRIP 2, JAN/82, PROB>|R| under HO:RHO=0, N=212

ENV'L FACTOR		SOSH	ALBAT	ALCID	SPETR	LGULL	BLKI	BIRD
SALINITY	Rs	-.24	+.14	-.36	+.13	-.24	-.18	-.41
	prob	.0004	.0484	.0001	.0621	.0001	.0094	.0001
	signif	**		**		**	*	**
TEMP	Rs	-.02	-.14	+.05	-.15	+.08	+.30	+.19
	prob	.7526	.0494	.4879	.0255	.2189	.0001	.0055
	signif						**	*
AREA	Rs	-.29	+.08	-.39	+.12	-.29	-.13	-.42
	prob	.0001	.2216	.0001	.0818	.0001	.0560	.0001
	signif	**		**		**		**

Table 9: Spearman rank correlation coefficients (Rs) of species-groups on salinity, temperature and area, by trip. Data base excludes two counts greater than 2000 and is limited to weather conditions when wind was less than 15 knots (1413 observations out of 1851). @ signifies a total lack of observations of a species from the study area, no meaningful correlation possible.

TRIP 3, MAR/82, PROB>|R| under HO:RHO=0, N=545

ENV'L FACTOR		SOSH	ALBAT	ALCID	SPETR	LGULL	BLKI	BIRD
SALINITY	Rs	-.09	-.05	-.21	-.05	-.15	-.08	-.18
	prob	.0470	.2924	.0001	.2602	.0004	.0726	.0001
	signif			**		**		**
TEMP	Rs	+.09	+.12	+.23	+.07	+.15	+.12	+.22
	prob	.0396	.0059	.0001	.1273	.0004	.0070	.0001
	signif		*	**		**	*	**
AREA	Rs	-.18	-.03	-.41	+.05	-.29	-.13	-.36
	prob	.0001	.4514	.0001	.2520	.0001	.0034	.0001
	signif	**		**		**	*	**

TRIP 4, MAY/82. PROB > |R| UNDER HO: RHO=0 N=179

ENV'L FACTOR		SOSH	ALBAT	ALCID	SPETR	LGULL	BLKI	BIRD
SALINITY	Rs	-.20	+.09	-.49	-.15	-.38	-.18	-.43
	prob	.0106	.2290	.0001	.0442	.0001	.0148	.0001
	signif			**		**		**
TEMP	Rs	+.12	-.10	+.43	+.09	+.36	+.18	+.37
	prob	.1241	.1796	.0001	.2440	.0001	.0132	.0001
	signif			**		**		**
AREA	Rs	-.33	+.19	-.55	+.05	-.45	-.25	-.45
	prob	.0001	.0112	.0001	.5489	.0001	.0006	.0001
	signif	**		**		**	**	**

Table 9: Spearman rank correlation coefficients (Rs) of species-groups on salinity, temperature and area, by trip. Data base excludes two counts greater than 2000 and is limited to weather conditions when wind was less than 15 knots (1413 observations out of 1851). @ signifies a total lack of observations of a species from the study area, no meaningful correlation possible.

TRIP 5, MAR/83. PROB>|R| under HO:RHO=0, N=111.

ENV'L FACTOR		SOSH	ALBAT	ALCID	SPETR	LGULL	BLKI	BIRD
SALINITY	Rs	0	-.04	+.09	0	-.11	-.40	-.15
	prob	1	.6477	.3437	1	.2368	.0001	.1251
	signif	@			@		**	
TEMP	Rs	0	+.01	-.10	0	+.13	+.40	+.16
	prob	1	.8790	.3138	1	.1899	.0001	.1019
	signif	@			@		**	
AREA	Rs	0	+.06	+.06	0	-.05	-.28	-.08
	prob	1	.5042	.5263	1	.6044	.0031	.4258
	signif	@			@		*	

TRIP 6, OCT/83, PROB>|R| under HO:RHO=0, N=99.

ENV'L FACTOR		SOSH	ALBAT	ALCID	SPETR	LGULL	BLKI	BIRD
SALINITY	Rs	-.54	+.19	-.44	-.05	-.35	+.31	-.33
	prob	.0001	.0565	.0001	.6295	.0004	.0017	.0008
	signif	**		**		**	*	**
TEMP	Rs	-.47	+.16	-.44	-.08	-.40	-.10	+.36
	prob	.0001	.1100	.0001	.4434	.0001	.3089	.0003
	signif	**		**		**		**
AREA	Rs	-.71	+.10	-.58	-.01	-.51	+.11	-.50
	prob	.0001	.3422	.0001	.9336	.0001	.2856	.0001
	signif	**		**		**		**

Table 10: Results of chi-square analyses for existence of relationships between presence/absence of birds, by species groups, and the two nominal variables; season and weather. There are four season categories, four weather categories and two categories for presence/absence; therefore degrees of freedom = (2-1)*(4-1) = 3 for both species groups and season and species groups and weather. N = 1101.

	SEASON		WEATHER	
SPECIES GROUPS	CHI2	prob.	CHI2	prob.
ALL BIRDS	36.1	.0001 ***	56.0	.0001 ***
SOOTY SHEARWATERS	92.4	.0001 ***	12.6	.0056 **
STORM PETRELS	165.9	.0001 ***	6.8	.0784 ns
ALCIDS	29.9	.0001 ***	26.5	.0001 ***
ALBATROSSES	32.9	.0001 ***	11.7	.0084 **
KITTIWAKES	28.6	.0001 ***	45.7	.0001 ***
LARGE GULLS	29.0	.0001 ***	33.0	.0001 ***

LARGE GULLS	season 1	season 2	season 3	season 4	sum
presence					
no	135	199	203	411	963
yes	26	60	25	42	138
	161	259	228	453	=1101

CHI-SQUARE=28.546 DF=3 PROB=0.0001

Table 10: [illegible]

SPECIES GROUPS	[illegible]	[illegible]	[illegible]	[illegible]
ALL BIRDS	[illegible]	[illegible]	[illegible]	[illegible]
SOOTY SHEARWATERS	[illegible]	[illegible]	[illegible]	[illegible]
STORM PETRELS	[illegible]	[illegible]	[illegible]	[illegible]
ALCIDS	[illegible]	[illegible]	[illegible]	[illegible]
ALBATROSSES	[illegible]	[illegible]	[illegible]	[illegible]
KITTIWAKES	[illegible]	[illegible]	[illegible]	[illegible]
LARGE GULLS	[illegible]	[illegible]	[illegible]	[illegible]

3.3 SUMMARY

From the preceding description of results, the major conclusions are:

1. Patterns are apparent, with almost all species groups being most numerous over the shelf.
2. Sooty shearwaters are generally absent from the study area during January and March.
3. The presence of birds in the study area appears most strongly related to season.
4. Weather may influence the observed numbers of birds, either through an effect on visibility or on the actual presence of the birds themselves.
5. Some species groups show correlations with temperature, salinity and offshoreness. The correlations, although apparently significant, vary with season and are not readily interpretable.

CHAPTER 4

DISCUSSION

This thesis explores the data from a pilot study of the distribution patterns of seabirds over a part of the northeast Pacific Ocean off Canada's west coast. The primary objectives were description of apparent seabird distribution patterns and tests of a set of research hypotheses that seabird occurrences, by species groups, are correlated with environmental factors, namely; salinity, temperature and distance offshore. The major themes of this discussion will be the apparent patterns detected, possible influence of weather and season, strength and direction of significant correlations, support of hypotheses, weaknesses in the research and recommendations.

4.1 APPARENT PATTERNS

The plots of species groups on latitude and longitude (Figures 7-12, Appendix) suggest that when all totals are considered, the greatest density of birds is in the shallow nearshore (shelf) zone extending to 20km off Vancouver Island. This trend is well illustrated along the latitude 50 row in Figure 12 by data from trip 6 (October 1983). For reference, the latitude/longitude cells 48/124, 49/124 and 49/126 contain a major portion of the nearshore shelf (area 1), while 52/132 lies near the southern tip of the Queen Charlotte Islands (in area 2). Alcids account for a large portion of the counts in these nearshore areas.

Vermeer et al suggest a density of 21.6 birds/km^2 for "pelagic waters off the west coast of Vancouver Island" (Vermeer et al, 1983, p.2) a zone apparently equivalent to area 2. In contrast, this study indicates average densities ranging from 0.9 to 38.7 birds/km^2 dependent on season, assuming perfect coverage of survey unit areas averaging .926 km^2, (300m wide by distance covered during 10 minute observation, 3087m at 10 knots).

Area 1, over the nearshore shelf, exhibits a range of 4.3 to 28.2 birds/km^2; area 2, 0.9 to 38.7 birds/km^2 (the extremes); and area 3, the distant offshore or pelagic zone, values from .62 to 1.7 birds/km^2. This pattern of lower densities over pelagic water(area 3) is consistent for all trips (Figure 25) and suggests that regardless of season the greatest concentration of seabirds will be found within 40km of the coast. The coincidence of this abundance with the position and bathymetry of the narrow contintental shelf off Vancouver Islands's west coast is probably related to the availability of food, but may also [illegible] portion of the [illegible] Ch [illegible] [illegible] [illegible]

V [illegible] for "pelagic [illegible] season [illegible] (Vermeer [illegible] In contrast, [illegible] this study [illegible] densities [illegible] 9 to 0.7 [illegible] season, [illegible] average [illegible] 1 minute [illegible]

At [illegible] the [illegible] of [illegible] (the extreme [illegible] zone, values [illegible] This [illegible] lower densities [illegible] for [illegible] season [illegible] within [illegible] abundance [illegible] and asymmetry [illegible] conditions [illegible] probably related to the availability [illegible] indicate the existence of unexplored patterns in the migration routes of species transient in this area. Further research is recommended.

Data for this study were collected during January, March, early May and October and fall outside the usual season of concentrated activity at breeding colonies (late May to late July) for most species breeding in the area, although storm-petrels may be found at colonies as early as March (Campbell, pers. comm.). The occurrence patterns noted above therefore probably have little dependence on colony position. Rather, they more likely represent use levels of these zones by both birds which breed elsewhere and are either transient or overwintering here and local breeders which disperse into the study area during the non breeding season.

The complete absence of sooty shearwaters in January 1982 and the very low counts in March of that year are consistent with their breeding/migration cycle which takes them to breeding colonies off South America (Guzman & Myres, 1983) or near New Zealand during the northern hemisphere's winter. Nonbreeders which might have remained in the northeast Pacific may have moved south of the study area with the seasonal shift of the 10 degree isotherm, an

[illegible]

further [illegible]

Data for [illegible] March, [illegible] concentration [illegible] as breeding colonies [illegible] May [illegible] July [illegible] most species [illegible] Although [illegible] colony position [illegible] they are [illegible] represent [illegible] breeding [illegible] species.

The [illegible] study [illegible] 1980 and [illegible] there to breeding colonies [illegible] New Zealand [illegible] which [illegible] with the [illegible] action possibly linked to the presence of saury (*Cololabis saira*) as suggested by Ogi (1982).

Although other patterns in the occurrence of seabirds apparently do exist, Figures 7 to 12, it is difficult to use regression analysis to reliably determine causal relationships with environmental factors, due to the influence of uncontrolled and unknown factors.

4.2 INFLUENCE OF SEASON AND WEATHER

Chi-square analyses (Table 7) show that a highly significant relationship exists between the observed numbers of most seabird groups (except storm-petrels) and weather conditions. This relationship needs further exploration to determine whether one particular component exerts a major influence. The results of at sea experiments suggest that, other factors being equal, wind has a large, though indirect, effect on the detectability of seabirds (Figure 29) so that, whether or not birds are actually present, their detectability may be altered, and in consequence abundance may be severely underestimated at higher wind speeds. Future research should address this problem.

A significant relationship was also found between season and seabird presence, for all species (Table 7). This was expected and is assumed to reflect the contribution to count totals made by migrants, concentrations of breeding adults within range of colony sites just before the breeding season, early post nesting dispersal patterns of adults (possibly with young, such as murres), seasonal foraging patterns and overwintering distributions. In view of the strong seasonal effect on all species groups indicated by chi-square tests and the apparent inconsistencies, trip to trip, in correlations between species groups and salinity, temperature and distance offshore (area), outlined below, it is probable that the greatest single factor controlling seabird abundance patterns is season.

4.3 CORRELATIONS

In this study the presence of correlations between the abundance of seabirds within species groups and three environmental factors (salinity, temperature and distance offshore) was hypothesized. Although lacking the power of a regression equation to predict the value of a dependent variable for any given value of an independent variable,

analysis for Spearman's rank correlation coefficients was chosen as the most appropriate technique since no assumption of distribution normality of the data could be made. Inherent to this technique is the caution necessary in interpreting any detected correlations. The fact that a correlation exists does not necessarily imply that the value of one variable (A) has occurred because of the value of the other variable (B) -- the correlation may work through another controlling factor (C) which influences both A and B or indirectly through some intermediate factor (D). In addition, the interpretation of a simple linked, possibly cause/effect relationship would not be justified if in fact bidirectional feedback existed. These conditions are modelled below:

1. simple correlation between a variable pair:

```
A---B
```

2. apparent correlation, but both controlled by an unknown factor outside the variable pair:

```
  C?
 / \
A   B
```

3. apparent correlation, but an unknown intermediate factor exists:

```
A--D?--B
```

4. apparent correlation, but bidirectional feedback occurs:

```
A---->B
 <----
```

Only in case one can interpretations suggest the existence of a cause and effect relationship, and then only when analyses [illegible] research [illegible] was chosen [illegible] technique [illegible] no assumption [illegible] validity of the data could be made. [illegible] in the [illegible] in interpreting [illegible] correlation [illegible] necessary [illegible] the value of one variable (A) [illegible] derived [illegible] the value of the other variable (B) [illegible] would work through [illegible] factor (C) [illegible] influencing both A and B [illegible] through some [illegible] (D). In addition, [illegible] interpretation [illegible] random [illegible] possibly [illegible] relationship would [illegible] groups [illegible] used. These conditions [illegible] as follows:

[illegible] simple correlation [illegible]

[illegible]

1. [illegible] relation [illegible] by an unknown [illegible] variable (C) [illegible]

C
B

2. [illegible] relationship [illegible] fact [illegible]

[illegible] A

3. [illegible] correlation [illegible] feedback occur

[illegible]

only in case [illegible] of [illegible] and [illegible] relationship [illegible] logic clearly indicates which variable plays the causal role.

Spearman's correlation coefficients (Table 8) indicate that for several species groups there are significant correlations between abundance and the environmental factors salinity, temperature, and offshoreness, although these correlations fluctuate trip to trip.

When trip (i.e. season) is controlled and within trip results are considered (Table 8) then each species group develops a correlation profile with salinity, temperature and area. Those correlations are discussed, by species group, below.

SOOTY SHEARWATERS maintained a weak to moderately strong negative correlation with salinity throughout all trips. Temperature showed an erratic correlation, being weak and positive (+.16) in October 1981 but negative and moderately strong (-.47) during October 1983. Correlation with area, an indicator of offshoreness, was consistently weak and negative (-.18 to -.33) for all trips except October 1983 when it became strongly negative (-.71). This suggests that the distribution of these shearwaters, particularly in late summer, may be more closely linked to salinity and distance from shore than to temperature. The evidence is not conclusive, however. Many observers note that this species is not commonly recorded close inshore, which suggests that the broad designations of areas one, two and three were too coarse to detect any decrease in numbers within 5 kilometers of the coast. This problem was additionally compounded by a paucity of data for area 1.

In passing it may be noted that a large, (~10,000) dense flock was observed actively feeding May 13, 1982, 19 kilometers west of Estevan Point, off the entrance to Nootka Sound. Guzman and Myres (1983) report similar large feeding aggregations for mid-May off the entrance to Clayoquot Sound, slightly to the south. Knowledge of the occurrences of these very large flocks, in the nearshore shelf zone, is probably of more value in preventing undesirable impacts on the species than many of the trends revealed by correlation analysis.

ALBATROSSES' (Laysan and black-footed) only significant correlation with salinity was weakly positive in January 1982. Temperature correlations were weak and negative in January '82 then weak and positive two months

later in March. This species also had little correlation with offshoreness (area). In summary, of the environmental variables examined for relationships with this species group only season is significant. Other factors not tested here may also have effects on the occurrence patterns of albatrosses.

The STORM-PETRELS (Leach's and fork-tailed) generally showed no correlation with salinity except for a weak negative relationship in May 1982. Only one correlation with temperature occurred, weak and negative, January 1982. As well only one area correlation showed significance, that of October 1981. On the whole, the distribution of storm petrels appears unrelated to factors of salinity, temperature, and offshoreness.

The ALCIDS consistently showed weak to moderate negative correlation with salinity. In contrast, their correlation with temperature varied from weak and negative (Oct 81) to weak and positive March 1982, to moderately strong and negative in October 1983. Correlation with offshoreness was consistently negative and varied from weak (-.17, Jan/82) to moderately strong (-.55, Oct/83). In summary, the numbers of alcids, particularly common murres, decrease with distance from the coast (almost absent from later in March. [illegible] with [illegible] [illegible] of the [illegible] [illegible] [illegible] [illegible] [illegible] only [illegible] [illegible] [illegible] also have [illegible] [illegible] other [illegible].

The [illegible] generally [illegible] [illegible] [illegible] correlation [illegible] temperature [illegible], [illegible] January [illegible] [illegible] significance, [illegible] of October 1981. [illegible] the [illegible] of salinity, [illegible] [illegible].

[illegible] negative correlation with salinity [illegible] correlation with temperature [illegible] [illegible] and positive [illegible] strong and negative in October [illegible] [illegible] was consistently negative and [illegible] [illegible] to moderately strong [illegible] In summary, the [illegible] of [illegible], particularly [illegible] [illegible] [illegible] the pelagic zone), decrease with increased salinity, and usually decrease with increasing temperature. However, firm conclusions regarding causal relationships are difficult to form.

The species group containing the LARGE GULLS showed a consistently negative correlation with salinity, strongest during Jan/82, May/82 and Oct/83 and weakest during Oct/81 and March/82. Weak to moderate positive correlations (+.15 to +.36) with temperature occurred during March and May of 82 while a moderate negative correlation (-.40) existed in October 1983. Correlations with offshoreness varied in strength from trip to trip but were always negative. Thus the strongest and most consistent correlation suggest that gull occurrences are dependent on distance offshore, being most numerous closer to the coast.

BLACK-LEGGED KITTIWAKES appear inconsistently correlated with salinity. For example, a moderate negative correlation occurred in March/83 but in October/83 there was a moderately weak positive correlation. This change in direction of correlation with salinity is unexplained. Correlations with temperature were consistently positive though weak.

When ALL BIRDS are taken as a single group their occurrences showed a weak to moderate consistently negative correlation with salinity and generally a weak positive correlation with temperature except during the October 1983 trip when a moderate negative correlation was present. Overall a weak to moderate negative correlation with area (i.e. distance offshore) existed except during the March/83 trip. I submit, however, that considering all birds in one group is of questionable value because the correlation of the total group to various environmental factors often combines and masks very real but opposing trends exhibited by the smaller separate species groups. Inevitably a loss of information results.

4.4 SUPPORT OF HYPOTHESES

Two relationships and three general correlations were hypothesized: (1) the observed presence of a species group is related to season; (2) the observed presence of a species group is related to weather; (3) there is a correlation between observed numbers of seabirds and salinity; (4) there is a correlation between observed numbers of seabirds and temperature; and (5) there is a correlation between observed numbers of seabirds and distance offshore.

When [illegible] (1980) [illegible] group [illegible]
[illegible] correlation [illegible] salinity [illegible]
correlation with temperature except during [illegible]
[illegible] moderate negative correlation [illegible]
Overall, [illegible] most [illegible] negative correlation [illegible]
(i.e. distance [illegible]) exists except [illegible]
[illegible] however, that [illegible]
group is of questionable value because [illegible]
[illegible] variable environment [illegible]
[illegible] and [illegible] opposing [illegible]
by the smaller [illegible]
of information needs.

4.4 SUPPORT OF HYPOTHESES

[illegible] general [illegible]
hypotheses: (1) the observed presence [illegible]
is related to [illegible]; (2) the observed [illegible]
station group [illegible] related to [illegible]
correlation [illegible] observed [illegible]
salinity; [illegible] correlation [illegible]
[illegible] of salinity and temperature, and (4) [illegible]
correlation [illegible] observed [illegible]
distance [illegible].

Based on results of chi-square analysis, the hypothesis that observed presence of a species group is related to season is accepted. All species groups are significantly related to season without exception.

All species groups except storm-petrels show significant relationship between observed presence and weather. Therefore the hypothesis that observed presence of seabirds is related to weather is accepted for sooty shearwaters, albatrosses, alcids, large gulls and black-legged kittiwakes but rejected for storm-petrels.

Correlations of observed numbers of each species group with salinity, temperature and area for separate trips (Table 9) provide varying support for the original hypotheses and are not readily summarized, except in one case. Observed numbers of storm petrels show no correlation with the three variables regardless of trip. Therefore, the hypotheses that observed numbers of storm-petrels are correlated with any of the variables salinity, temperature, or distance offshore are rejected.

[illegible] analysis [illegible] hypothesis, that observed [illegible] vole [illegible] season [illegible] significantly related to season [illegible].

All [illegible] species [illegible] groups [illegible] storm patterns [illegible] significant relationship between observed [illegible] weather. Therefore [illegible] hypothesis [illegible] relationship between [illegible] Sheetwater [illegible] [illegible] accepted [illegible] but rejected [illegible].

Correlations of observed numbers of [illegible] groups [illegible] activity [illegible] (Table 9) provide [illegible] hypotheses [illegible] not necessarily [illegible] observed numbers [illegible] with the [illegible] variables [illegible]. Therefore, the hypothesis [illegible] observed numbers of [illegible] correlated with [illegible] variables [illegible] or [illegible].

4.5 WEAKNESSES AND UNRESOLVED PROBLEMS

Within the lexicon of Hurlbert (1984), this thesis might be classed as a comparative mensurative experiment, a type of survey or census as opposed to manipulative or true experiments. Inferential statistics therefore, though possible, are limited and certain caveats must be expressed regarding the weaknesses of the research.

During analysis it became apparent that certain weaknesses in the research would preclude the formation of meaningful conclusions applicable beyond the circumstances of the particular cases examined in this thesis. These weaknesses are; lack of data, inadequate replication of transects, inadequate control or at least measurement of factors affecting the collection of data (wind speed, sea state, target gray tone, target size) and unresolved difficulties of counting seabirds at sea. Many other problems, ancillary to this thesis, remain unresolved as well.

The fundamental weakness is the lack of sufficient data. The effect is apparent when attempts are made to sort the data into subsets relatively homogeneous with regard to any set of controls while allowing sufficient divisions along any one variable's spectrum of values to

4.5 WEAKNESSES AND UNRESOLVED PROBLEMS

[illegible]

[illegible]

[illegible]

sensitively detect significant variations. For example, the assessment of the effect of salinity on the abundance of tufted puffins, other factors held constant, would be best conducted when season, area, weather, and temperature were controlled. Acknowledging that it is impossible to actually control them, the next best alternative is pseudo-control--subsetting the data so that the variation in each factor is held within some specified range. Given four seasons, three areas, at least four weather types and, on average, thirty to fifty temperatures (rounded to nearest 1/10 degree) results in 1400 to 2400 subsets of observations. Replication compounds the problem. Since only 1851 observations were available, consideration of infrequently occurring species such as tufted puffin was impossible as were subsets based on small temperature intervals. As an alternative, related species were combined as species groups, and temperature intervals were generally created by rounding to nearest whole degrees. These steps had the effect of reducing numbers of subsets to about 200, while allowing tests for correlation between salinity and combined alcids (in contrast to only tufted puffin above). Something on the order of ten observations might be available for the test. In fact, while correlations were calculated neither salinity nor temperature were controlled, only trip (i.e. season), with an accompanying per case increase in observations but a decrease in the level of information obtainable.

It follows from the above that although correlations between certain species groups and salinity (for example) do occur with some significance the inference that changes in bird abundance can be linked to changes in salinity is undermined by the unknown influence of temperature (a potential TYPE 2 correlation misinterpretation, Section 4.3 above). Parallel situations exist for other variables.

4.5.1 Difficulties of Counting Birds at Sea

The major problems associated with assessing abundance of birds at sea may be generalized to methodological replicability, visibility, and bias. Over the last several decades methods of counting seabirds at sea have evolved from counting birds/day (Jesperson 1924), to birds/hour in a 180° arc (Wynne-Edwards 1935, Tickell & Woods 1972), to birds/hr and birds/mile (Gould) in 1974. Since then the perceived insensitivity of hour units to complex oceanographic variations led to the use of 10 minute periods by Brown et al (1975) with a 180° survey arc, later refined somewhat by Bourne (1976) who limited the scan area to a 90° arc, bow to beam. By 1984 the use

of the 10 minute observation period and the 90 degree bow to beam sector scan had been generally adopted in seabird survey methods around the world (Tasker et al, 1984). In spite of this, other problems of methodological replicability among studies and the pervasive difficulty of eliminating, controlling or compensating for sources of error make it difficult or impossible to compare results in meaningful ways.

Three sub-problems are (a) the lack of a general acceptance of a standard transect width, (b) the assumption that all birds within it can be detected and (c) the elimination of bias. Ignoring for the moment what would be appropriate as a standard transect width the other two problems have their sources in five, often interrelated factors: size, colour, behaviour, weather (including sea condition) and observer ability. Dixon (1977) and Powers (1982) reported on the effects of several of these factors. Their points are incorporated in the paper of Tasker et al (1984) who suggest three methods, outlined below, for a standardized approach to counting seabirds at sea.

Method I, the most sophisticated, comprises four routines:

(a) First is a count of all birds on the sea within [illegible] ob[illegible] [illegible] and the [illegible] [illegible] second occasion and [illegible] [illegible] stated [illegible] [illegible] methods [illegible] [illegible] quite [illegible] [illegible] bias [illegible] reliability [illegible] and [illegible] [illegible] elementary contribution [illegible] error make it difficult [illegible] impossible to compare [illegible] meaningful way.

Since [illegible] the [illegible] approach [illegible] traditional [illegible] assumption that [illegible] elimination [illegible] techniques [illegible] two procedures [illegible] behaviour [illegible] correlation and [illegible] 1972 [illegible] Their [illegible] 1980 [illegible] standardized approach [illegible] counting [illegible]

Method [illegible]

[illegible]

a defined band transect 300 meters wide with inner divisions at 200 and 100 meters, with counts made continuously in a series of ten minute observations. Results should be expressed as BIRDS ON THE SEA PER UNIT AREA.

(b) Separately, an instantaneous count of flying birds within a defined transect, as in (a), is made; results expressed as FLYING BIRDS PER UNIT AREA.

(c) A third separate count is made of birds moving across the bows of the ship when large flocks are encountered (e.g. sooty shearwaters flocks of 10,000 to 500,000) which stream across the track of the vessel but are not well sampled within the transect.

(d) Birds associated with the ship (typically gulls and albatrosses) are recorded separately and not used in bird density calculations.

Method II is essentially a count of all birds seen to the limits of unaided visibility in a 90 degree bow-beam arc per ten minutes (or converted to birds/distance unit). This technique detects rarer species more effectively than Method I and produces results comparable with those of many earlier studies.

Method III, conforming to the Pacific Ocean Biological Survey Program (Gould, 1974) counts all birds seen in a 360 degree scan, recorded over ten minute intervals.

Although all three methods may be employed simultaneously when bird densities are low, the latter two a [illegible] 500 [illegible] the [illegible] and [illegible] continuously [illegible] series [illegible] UNIT AREA.

(b) [illegible] within a defined [illegible] results [illegible] FLYING [illegible]

(c) [illegible] separate counts in each [illegible] across [illegible] of the [illegible] encountered (e.g. [illegible] the numbers [illegible] to 500, [illegible] across the [illegible] vessel, but [illegible] not [illegible] sampled with [illegible]

(d) Birds associated with the ship [illegible] used [illegible] density calculations.

Method [illegible] count of all birds [illegible] limit [illegible] visibility [illegible] per ten minutes [illegible] for [illegible] birds [illegible] This [illegible] species [illegible] Method [illegible] results [illegible] earlier studies.

Method [illegible], conforming [illegible] Ornithological [illegible] Programme [illegible] [illegible] 90° [illegible] scan, [illegible] intervals.

With each [illegible] three [illegible] small [illegible] hand [illegible] should be dropped as densities increase. Method I, alone, gives the best estimates of densities of seabirds at sea for shipboard surveys.

The variability of distances at which seabirds can be seen on the sea surface under changing conditions of weather, seabird size and seabird gray tone was not adequately controlled. This potential source of error was recognized early in the research and attempts were made to isolate and analyze the influence of three variables; wind speed, visibility, and precipitation. Unfortunately, only dichotomous values were recorded for each so that meaningful regressions could not be calculated.

Of the three factors wind appeared to have the most significant effect and therefore further analyses for Spearman correlations were limited to those observations where wind had been less than 15 knots during the data collection.

Analysis of visibility data lead to preliminary conclusions on the effects of several factors on the visibility of small objects at sea. Effects of the following factors were considered: wind speed, target size, observer elevation above sea level, target gray tone.

With other factors held constant visibility distances are greatest when wind is lowest, size largest and gray tone lightest. Visibility distance is greatest at the higher observation position, except in the case of small dark objects when visibility is marginally greater from a lower position. This was unexpected but probably results from an increase in the silhouetting of the target against the horizon on the crest of swells, an aid to visibility for an observer on the bottom deck, in contrast to the difficulty of separating a dark target from the generally dark background of water filling the field of view of an observer on the bridge deck.

Other problems of seabird visibility are related, in no particular order, to the following:

1. the tendency of alcids to dive as an escape response, potentially disappearing from view unobserved, resulting in significant underestimates of that species group;
2. the tendency of gulls and albatrosses to approach and follow ships, resulting in probable overestimates of those species;
3. greater visibility of flying birds, particularly light coloured ones , again leading to overestimates of gulls, kittiwakes and light phase fulmars for

example;

4. bird behaviour, particularly attraction to and participation in mixed species feeding flocks;

5. observer training, experience and ability;

6. lighting conditions, particularly sun glare;

7. physical limit to human vision;

8. unknown effects of weather on activities of seabirds.

Intuitively one might assume that birds would avoid stormy weather at sea, from a bioenergetics point of view. However, although visibility is reduced during stormy weather and for that reason counts may decline, there is no conclusive evidence that all or most species shift away from storms. Indeed some species may be attracted to storms for reasons unknown but possibly related to migration (Guzman & Myres, 1983). Summers (in Guzman & Myres, 1983) observed flocks of sooty shearwaters flying northwest past Brooks peninsula in a southeast gale, wind ~35 knots, an event which suggest that at least some birds use winds as an aid in migration. For now the issue remains unresolved and no firm conclusion is possible.

4.6 RECOMMENDATIONS FOR FUTURE WORK

Several fundamental questions in seabird research remain unanswered. Are seabirds important, and if so, why? Do they have an economic value? What is it or how can it be assessed? How can our knowledge of seabirds be most efficiently increased? Do both coastal and inland residents value seabirds, in either reality or imagination, as a requisite element in their respective images of the coastscape? Can the value of seabirds be quantified with, for example, total expenditures on offshore and coastal birding excursions divided by observed seabird populations yielding a value per bird or per colony? If the answers to these questions support the premise that there is substantial public interest in seabirds then seabird research, which is expensive, can present a strong argument for funding. Let us assume that money is available and that we may speculate on future research.

The relationships between seabirds and both Canadian and global fishing industries are not clear. Efforts towards understanding the effect of major offshore breeding colonies, such as Triangle Island, on fish in surrounding areas as well as potential links between migratory waterfowl (eg. brant), eelgrass beds and juvenile salmon should be considered. Continued work is also recommended on seabird mortality caused by net fishing.

The density of seabirds, by species, per unit area is usually a required value in calculations to determine, for example, input of fecal material to the marine system or biomass in a given area. A central problem in density assessments is the difficulty of determining what proportion of birds present in a survey area are actually observed. Dependent on this factor are the population estimates of various species. Inconspicuous birds are typically underestimated. Contributing to this problem are the biasing effects of bird size and colour and weather (particularly the formation of white caps). Solution of this problem would benefit seabird research, particularly if it included the creation of a table of correction values for use under typical ranges of each variable: e.g. for small alcids: true pop. = observed count * (correction for size) * (correction for colour) * (correction for sea state or weather) * (correction for observer elevation).

Pilot tests indicate that data useful in the derivation of visibility coeficients can be obtained in relatively simple experiments using balloons to simulate seabirds on the water. The following experiment is suggested:

> Inflate and water-ballast 20 balloons for each combination of these conditions; 3 sizes (10, 15 and 20 cm diameter), 3 gray tones (white, medium gray and black), 3 observer elevations above sea level (3, 6 and 9 m), 3 sea states (calm, rippled, choppy/whitecaps), 3 swell conditions (<2, 2-4 and >4 m) and 5 wind speeds (0-10, 11-20, 21-30, 31-40 and 41+ km/h). Position several independent observers of equal ability at each observer elevation on a ship moving at a constant speed, preferrably in the range of 15 to 20 km/h. Drop the balloons from the stern of the ship, alternating gray tones and sizes to minimize uncontrolled variations due to changing weather or lighting conditions. Record time to disappearance of each balloon and convert to distance travelled. For a given combination of sea state, swell and wind there will be 540 observations (20 per cell in a 3 by 3 by 3 matrix), requiring about a day of effort. Replication under all combinations of sea, swell and wind adds three more dimensions to the matrix and would require 44 more days of effort (24,300 observations, total).
>
> Analyze data for regressions of target visibility on gray tone, size, observer elevation, sea state, swell height and wind speed.

Pelagic seabird research requires some form of regular, preferrably inexpensive, access to the study area. Many early researchers (Jesperson, 1924) took advantage of ships of opportunity and collected data which were unique to a time and route unduplicated since. Although comparison of results from such studies is difficult, the advantage of travel on ships of opportunity in the future should not be ignored. The problems might be alleviated through a two part solution.

First, establish internationally agreed survey areas/routes transected regularly by ships, usually freighters. Acceptable transect routes should fall within a broad corridor containing major shipping routes. Then, within these formally recognized study areas establish a standardized survey procedure such as that recommended by Tasker et al (1984) and encourage international exchanges of data between maritime nations, each nation being responsible for areas off their own coast. At least one seabird observer (preferrably two) should traverse the route once every two weeks. This proposal requires that observers be of equal skill and expertise or that some form of comparison between observers be regularly made to ensure that data are within an acceptable range of compatibility.

Alternative data collection techniques include the posting of observers at fixed offshore sites (eg. drill rigs), remote islands and coastal headlands. It is speculated that conversion factors would be necessary to render point data compatible with transect data. Since data from fixed sites may give a better view of temporal change it is recommended that a few such sites be incorporated in the design of any study. Remote, manned lighthouses (eg. Estevan Point and Cape Scott on the BC. coast) would probably be suitable sites at which to place

that, [illegible] ty
[illegible] that [illegible]
[illegible]
[illegible] this [illegible] organized study [illegible]
standardized [illegible]
[illegible] data [illegible] between [illegible]
[illegible] observer [illegible] certainly [illegible]
route [illegible] two weeks. [illegible]
observers of equal skill [illegible]
of comparison [illegible]
[illegible]

All [illegible]
nesting [illegible] fixed [illegible]
rigs, [illegible]
[illegible] factors [illegible]
center point [illegible] commonly [illegible]
data from [illegible]
change [illegible] recommended that [illegible]
incorporated [illegible]
[illegible] point [illegible]
[illegible] would [illegible]

trained observers.

Myres (1972) described radar images of suspected flocks of migrating birds, possibly brant or sooty shearwaters off NW Vancouver Island. However, it is unlikely that existing coastal radar facilities such as those used by the Vessel Traffic Management (VMT) centre, Ucluelet, BC. would be able to detect seabirds. At least part of the difficulty stems from the VTM's use of S-band radar whose relatively long wavelengths make the resolution of small objects difficult (Pokeda, pers. comm.). On the other hand X-band radar, with a 3 cm wavelength, would be more suitable for bird detection but apparently is not as effective for long range scanning (Reeves, Anson & Landen, 1975). Nevertheless, the use of radar as a tool for the detection of large flocks of migrants should be explored further although its use in assessing seabird densities is not recommended. (It is recognized that the most technically sophisticated equipment will probably be under military restriction and not available for uncontracted research.)

Other areas of recommended research are: analysis of the post breeding arrival of common murres at the mouth of Barkley Sound; estimation of populations of marbled murrelets and their possible role in forest fertilization through transfer of fish to nesting areas and investigation of the feasibility of using low-altitude aerial survey techniques for rapid synoptic assessment of seabird populations over distant pelagic waters (1000+ km offshore).

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G[illegible] D. R[illegible] (Puffinus [illegible]) [illegible] the [illegible] Canada [illegible]

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APPENDIX

Table 11: List of seabird common names used as variables with equivalent scientific names, from Harrison (1983).

Common name	Scientific name
arctic loon	Gavia arctica
black-footed albatross	Diomedea nigripes
Laysan albatross	Diomedea immutabilis
northern fulmar	Fulmaris glacialis
sooty shearwater	Puffinus griseus
Buller's (New Zealand) shearwater	Puffinus bulleri
fork-tailed storm-petrel	Oceanodroma furcata
Leach's storm-petrel	Oceanodroma leucorhoa
mottled (scaled) petrel	Pterodroma inexpectata
long-tailed jaeger	Stercorarius longicaudis
pomarine jaeger	Stercorarius pomarinus
parasitic jaeger	Stercorarius parasiticus
phalarope sp.	Phalaropus sp.
glaucous-winged gull	Larus glaucescens
California gull	Larus californicus
herring gull	Larus argentatus
mew gull	Larus canus
Bonaparte's gull	Larus philadelphia
Sabine's gull	Larus sabini
black-legged kittiwake	Larus tridactyla
common murre	Uria aalge
marbled murrelet	Brachyramphus marmoratus
ancient murrelet	Synthliboramphus antiquum
pigeon guillemot	Cepphus columba
Cassin's auklet	Ptycoramphus aleuticus
rhinoceros auklet	Cerorhinca monocerata
tufted puffin	Lunda cirrhata
brant sp.	Branta sp.

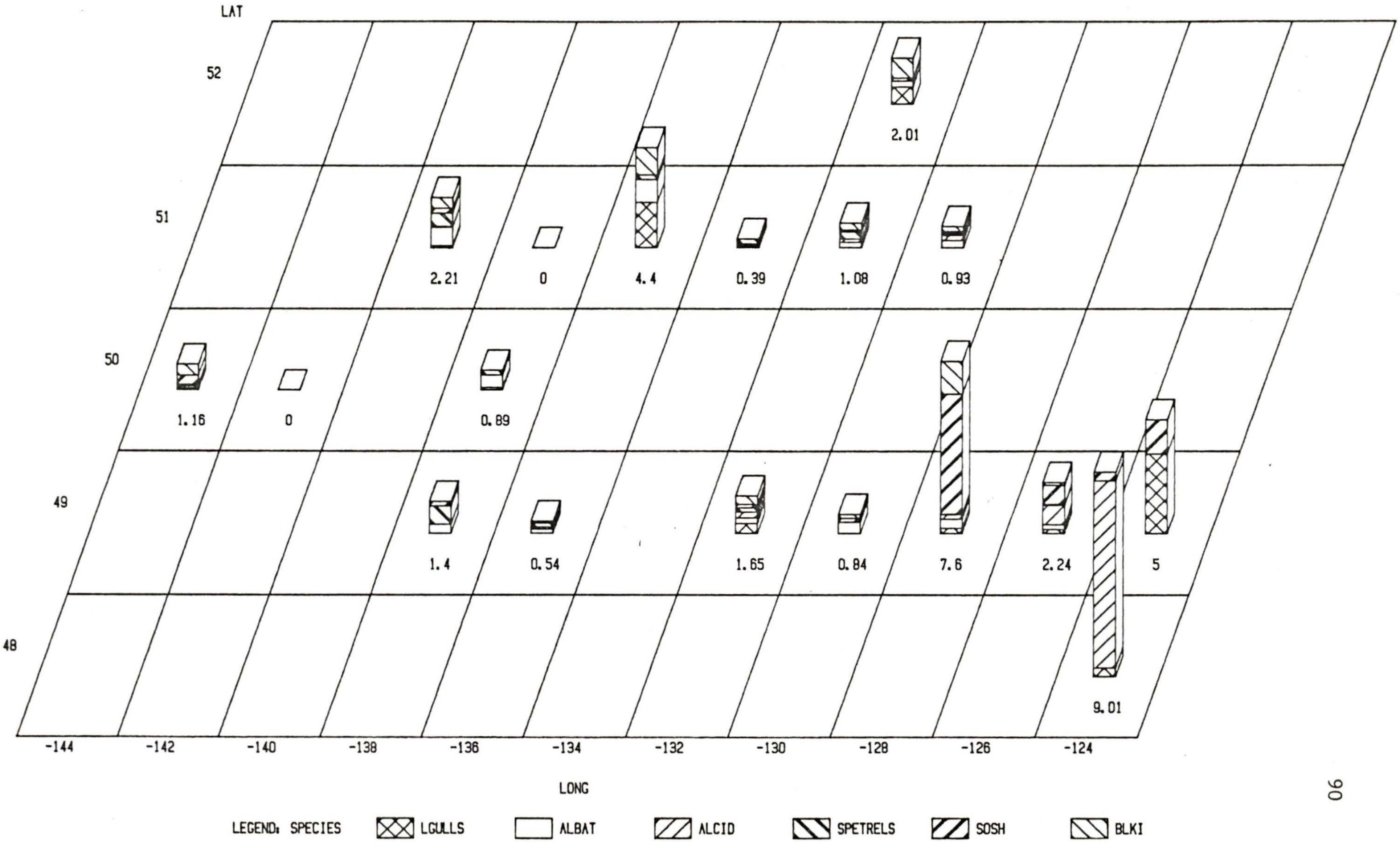

Figure 7: Block chart of mean species counts per 10 minutes, in lat/long cells. Sums of the six species means are below bars. Trip1

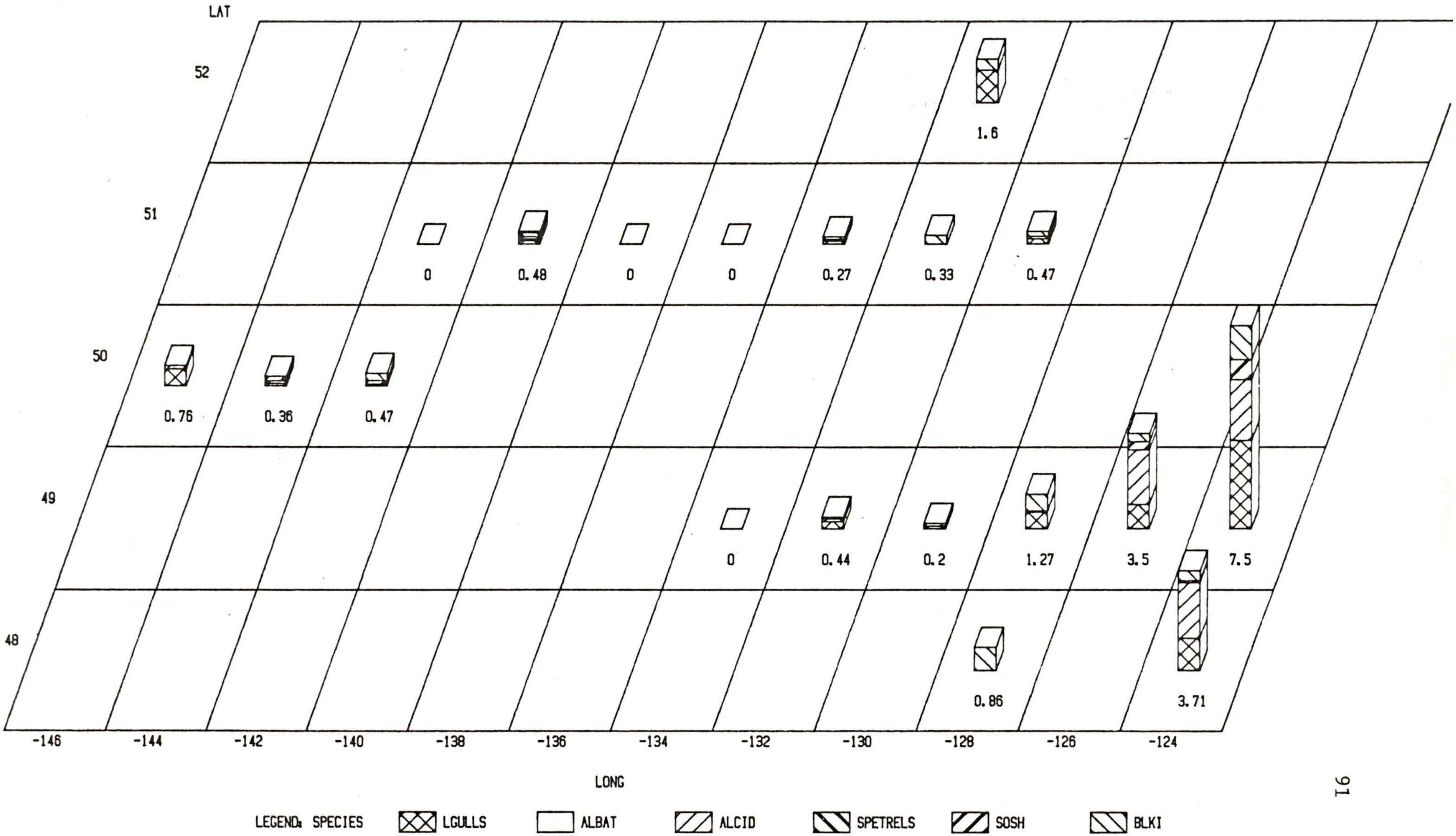

Figure 8: Block chart of mean species counts per 10 minutes, in lat/long cells. Sums of the six species means are below bars. Trip2

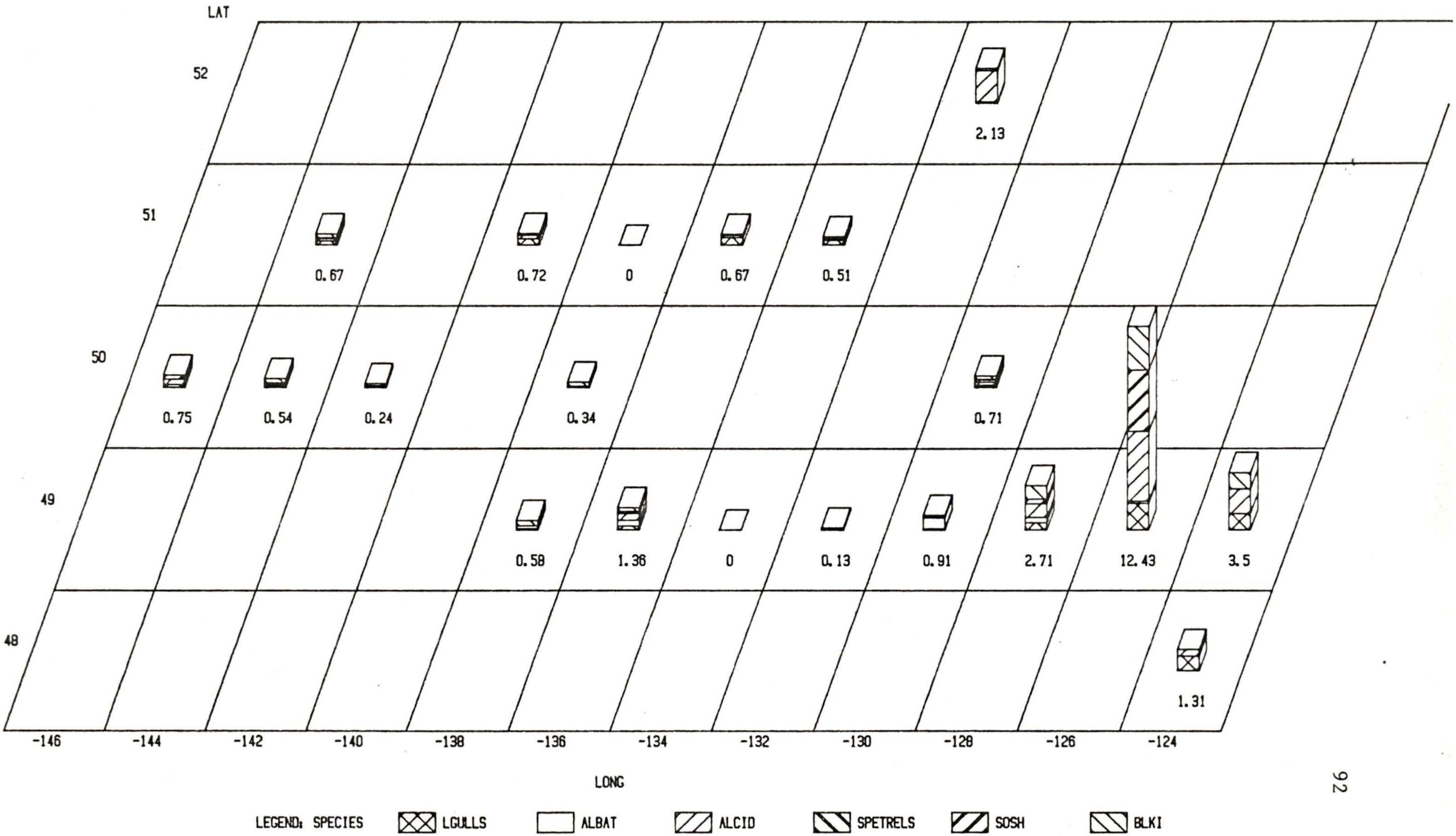

Figure 9: Block chart of mean species counts per 10 minutes, in lat/long cells. Sums of the six species means are below bars. Trip3

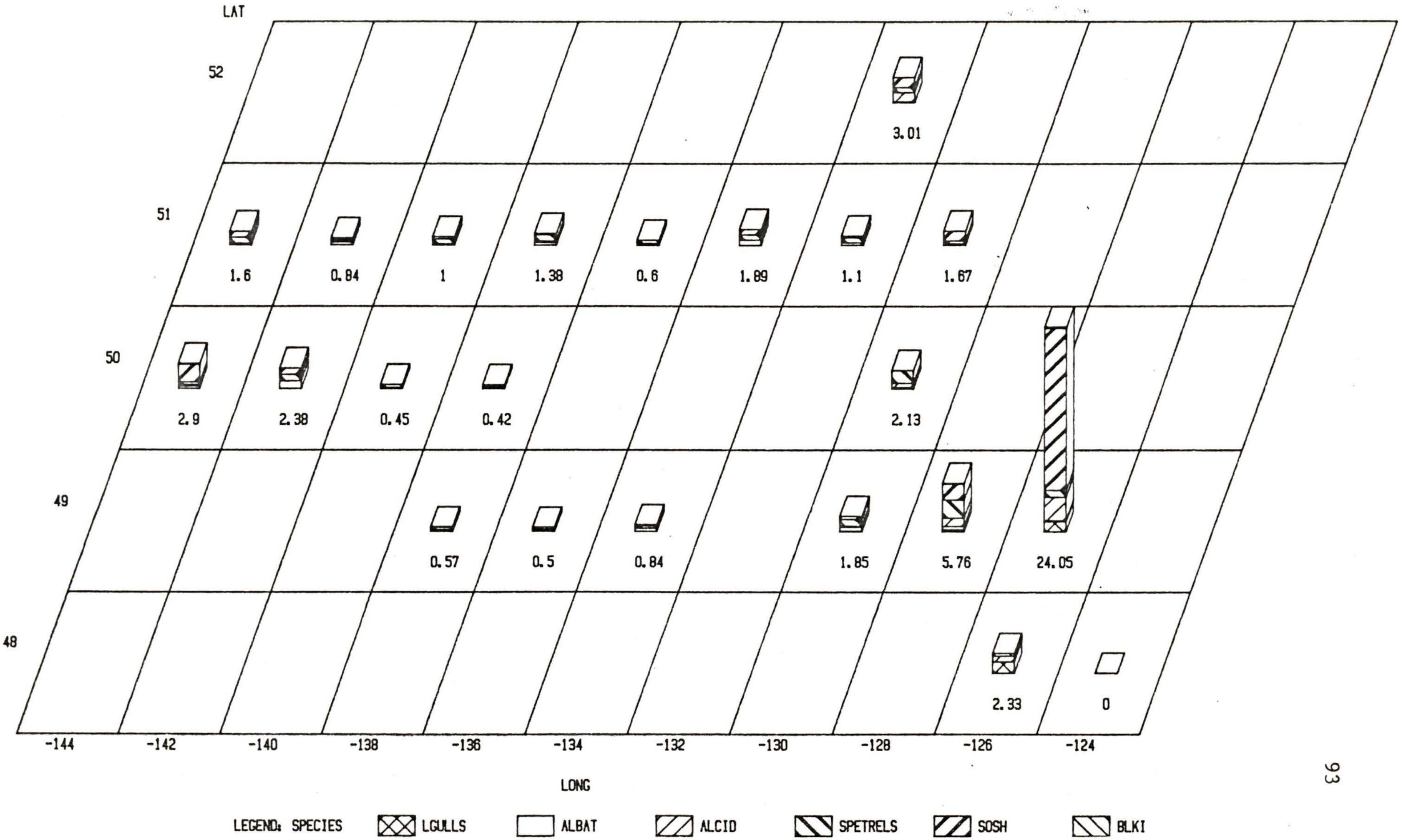

Figure 10: Block chart of mean species counts per 10 minutes, in lat/long cells. Sums of the six species means are below bars. Trip4

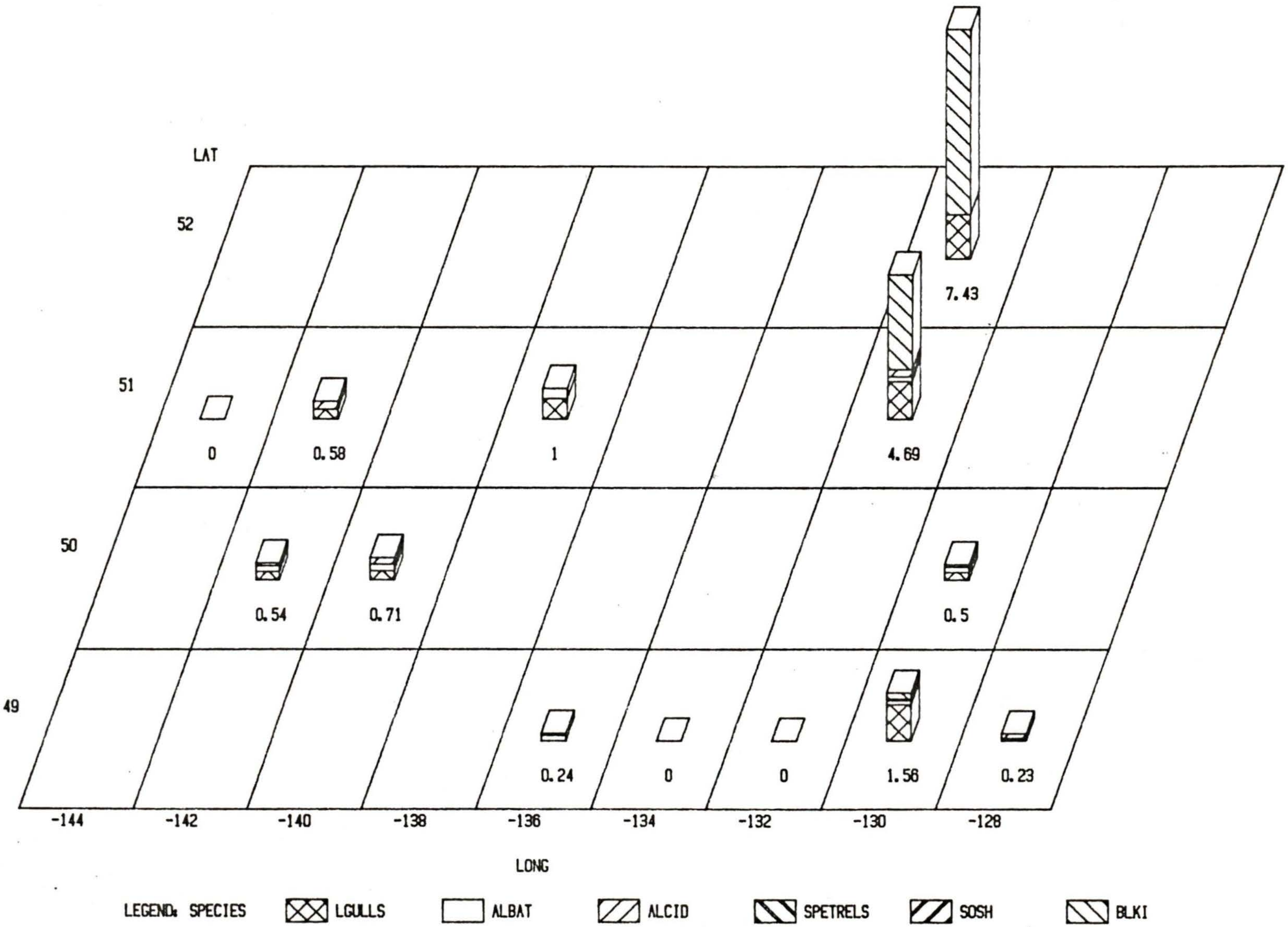

Figure 11: Block chart of mean species counts per 10 minutes, in lat/long cells. Sums of the six species means are below bars. Trip5

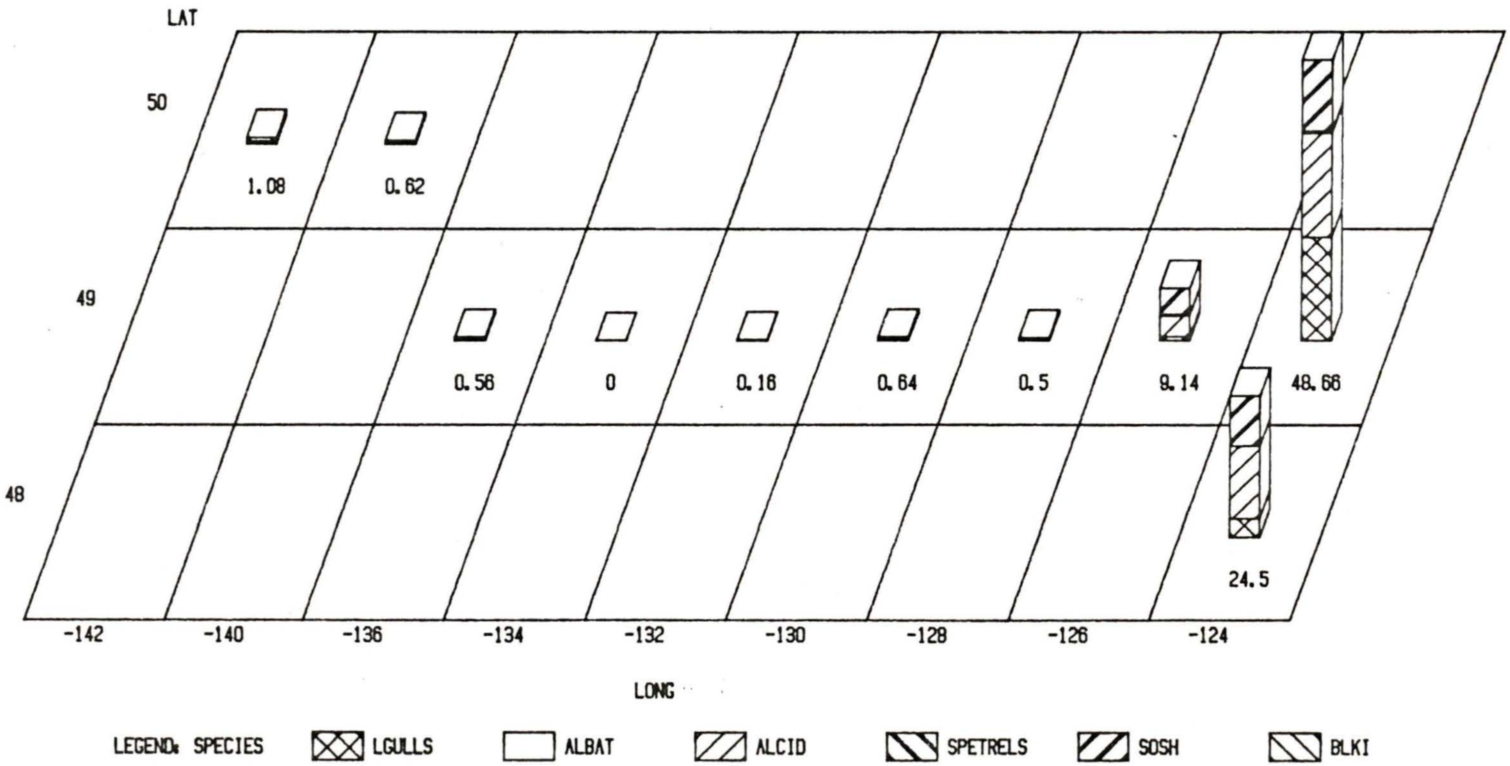

Figure 12: Block chart of mean species counts per 10 minutes, in lat/long cells. Sums of the six species means are below bars. Trip6

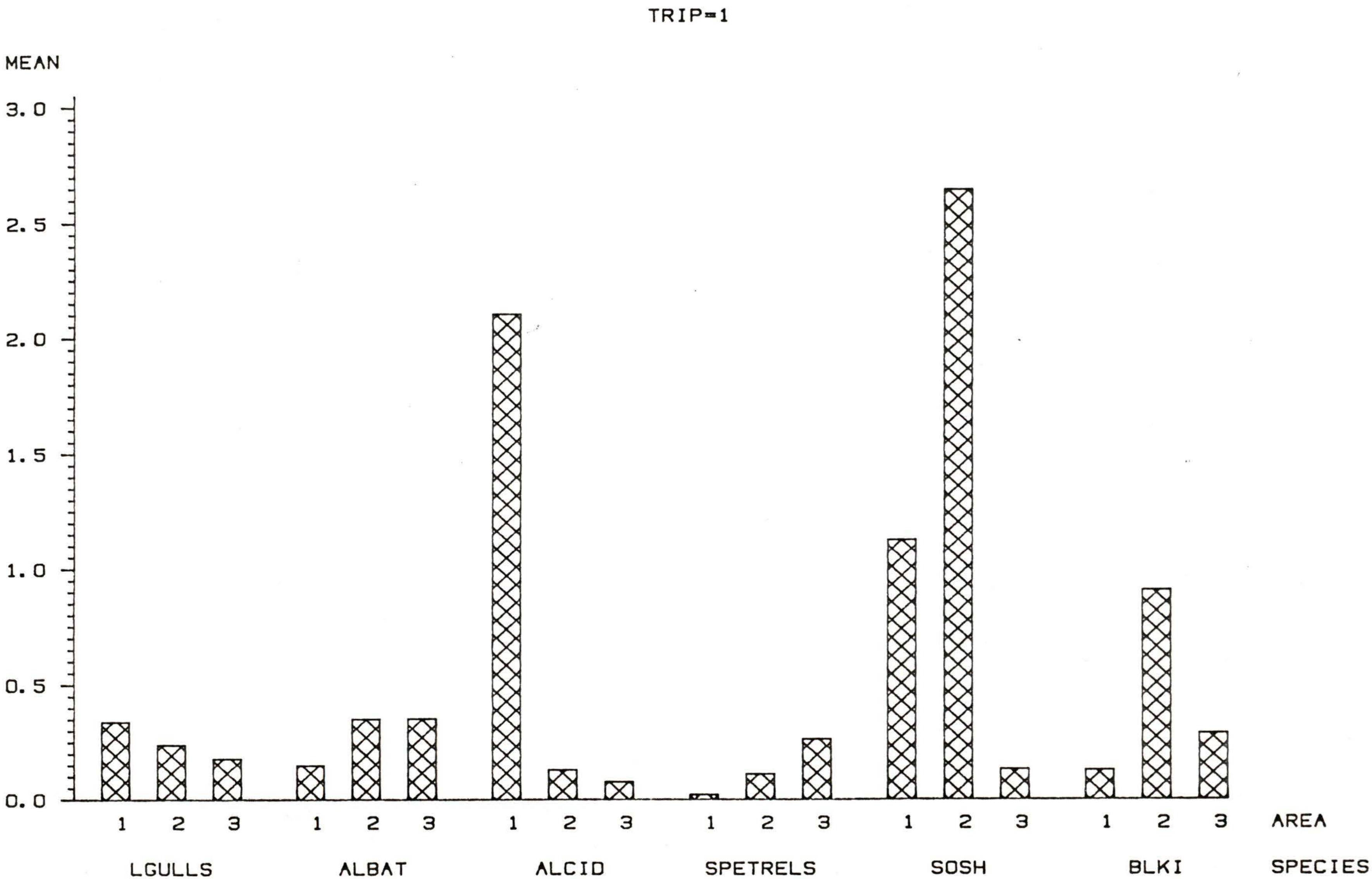

Figure 13: Bar graphs of mean species counts per 10 minutes, in areas ranked by distance offshore (3=farthest offshore). Trip 1

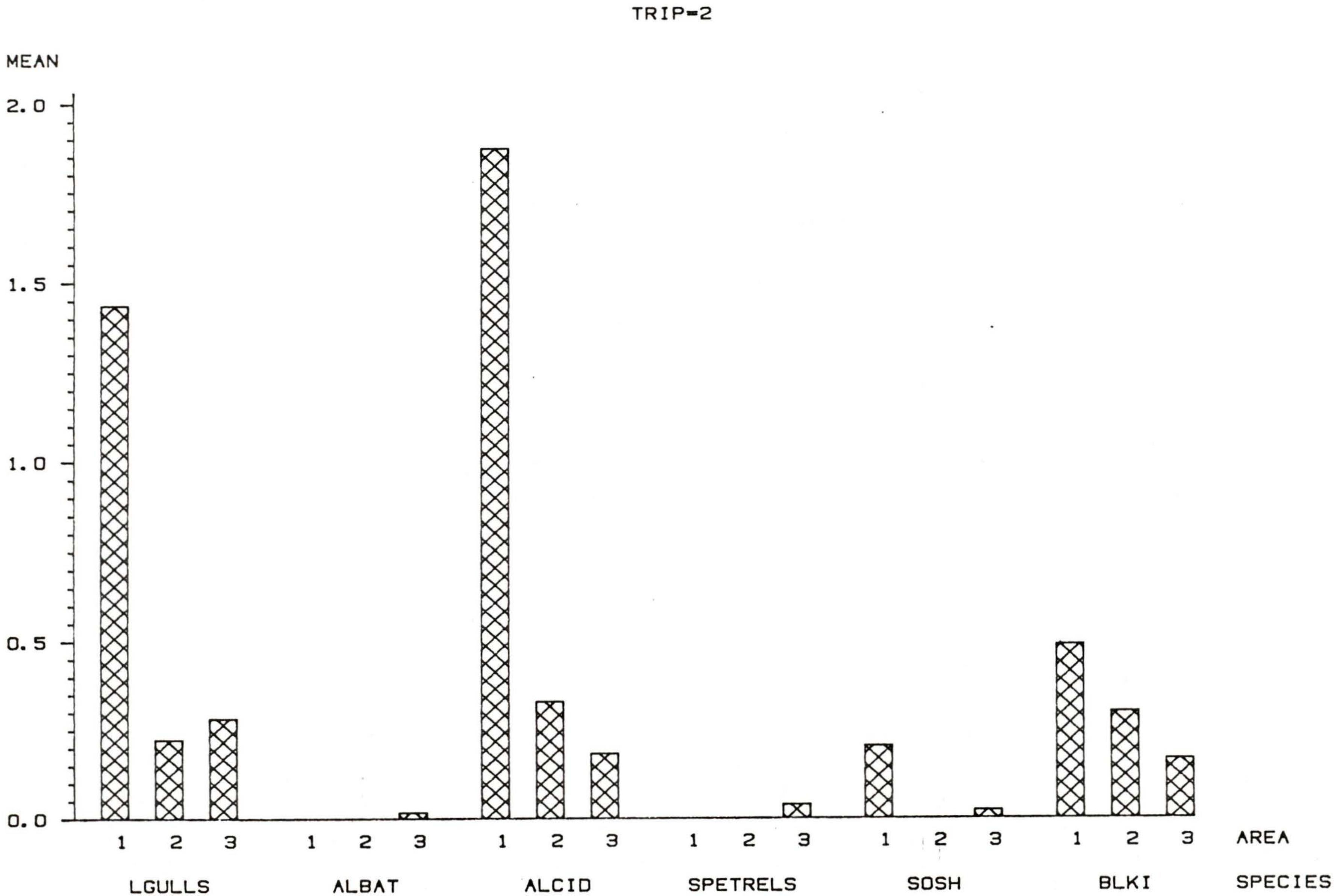

Figure 14: Bar graphs of mean species counts per 10 minutes, in areas ranked by distance offshore (3=farthest offshore). Trip 2

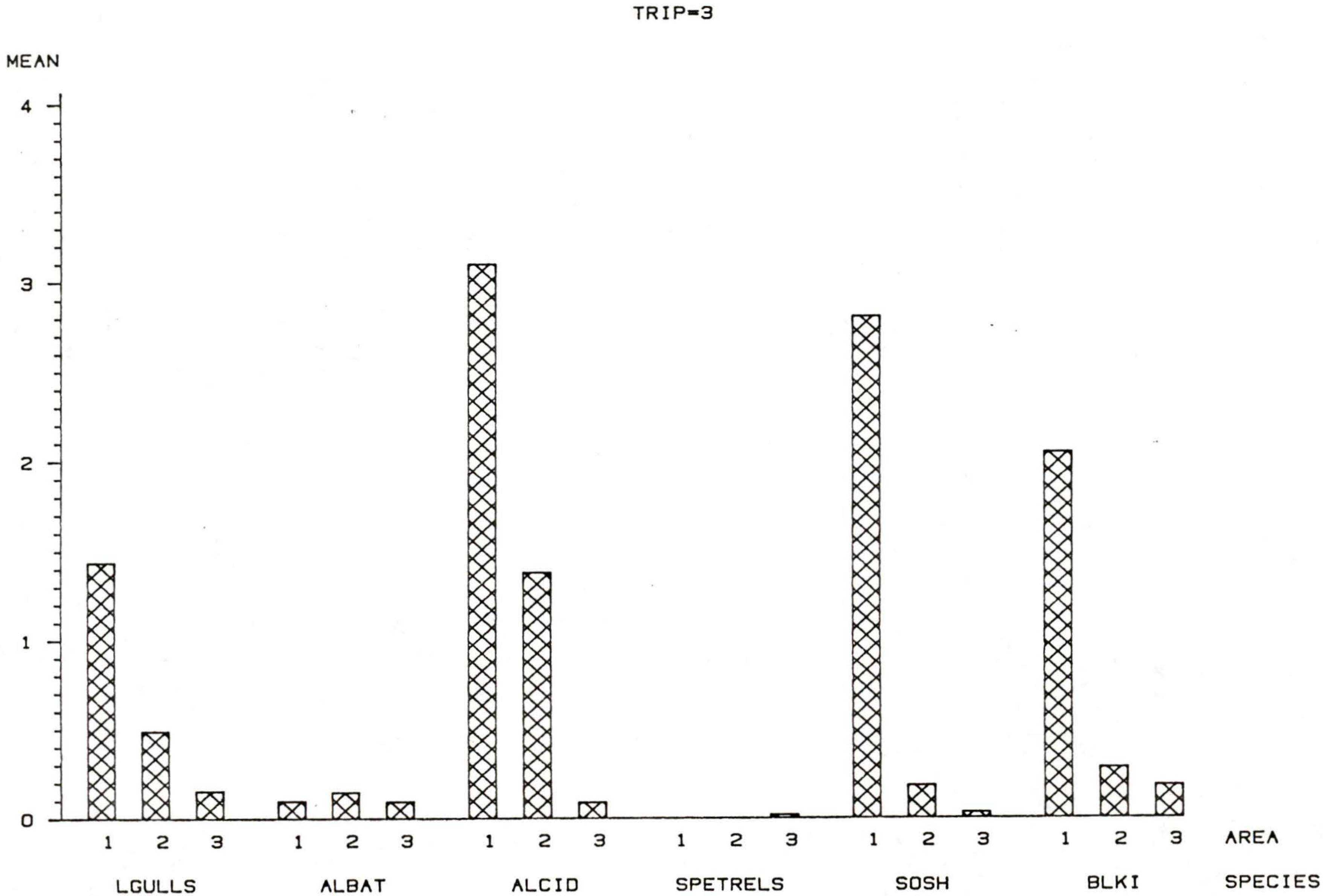

Figure 15: Bar graphs of mean species counts per 10 minutes, in areas ranked by distance offshore (3=farthest offshore). Trip 3

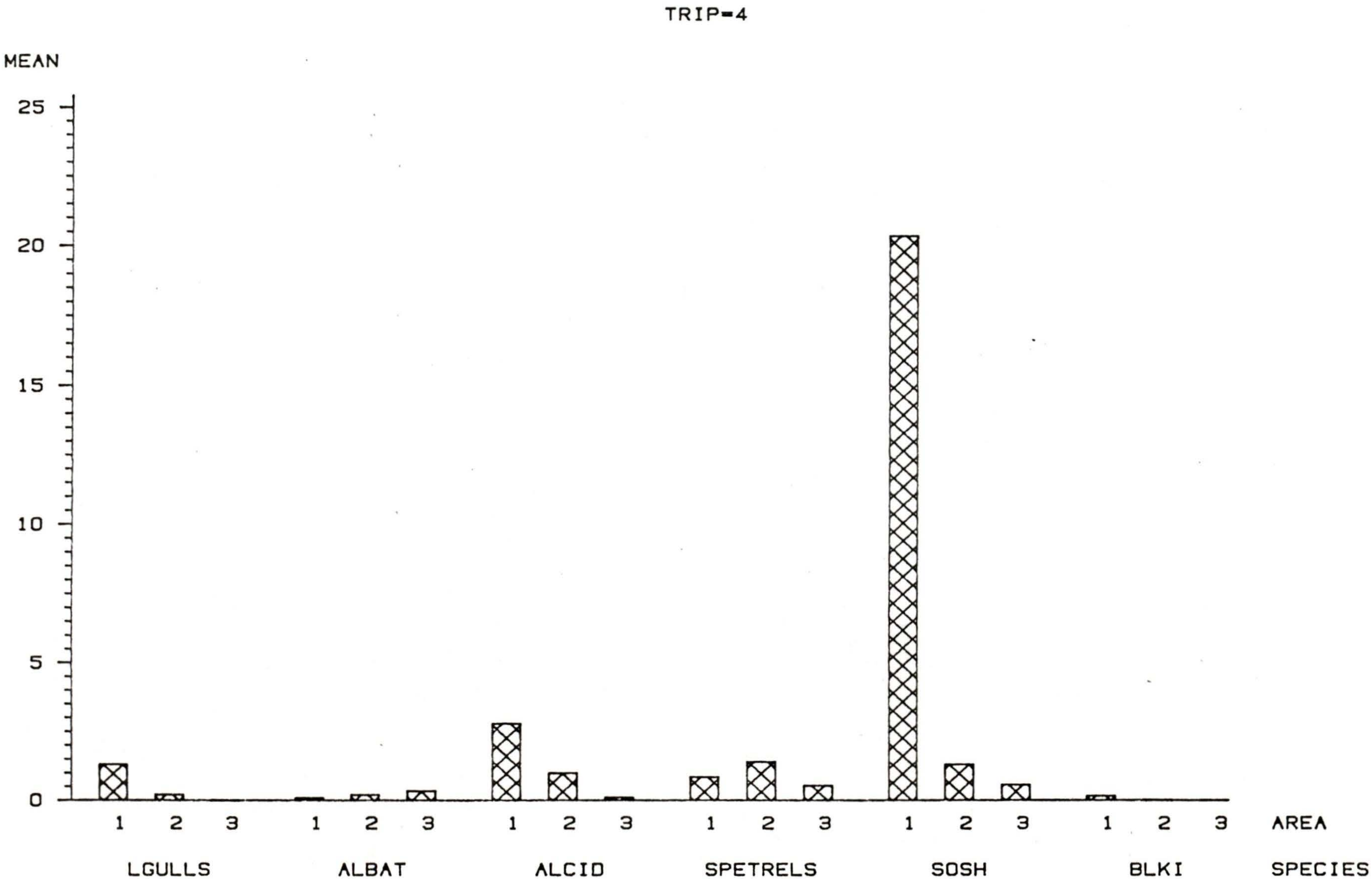

Figure 16: Bar graphs of mean species counts per 10 minutes, in areas ranked by distance offshore (3=farthest offshore). Trip 4

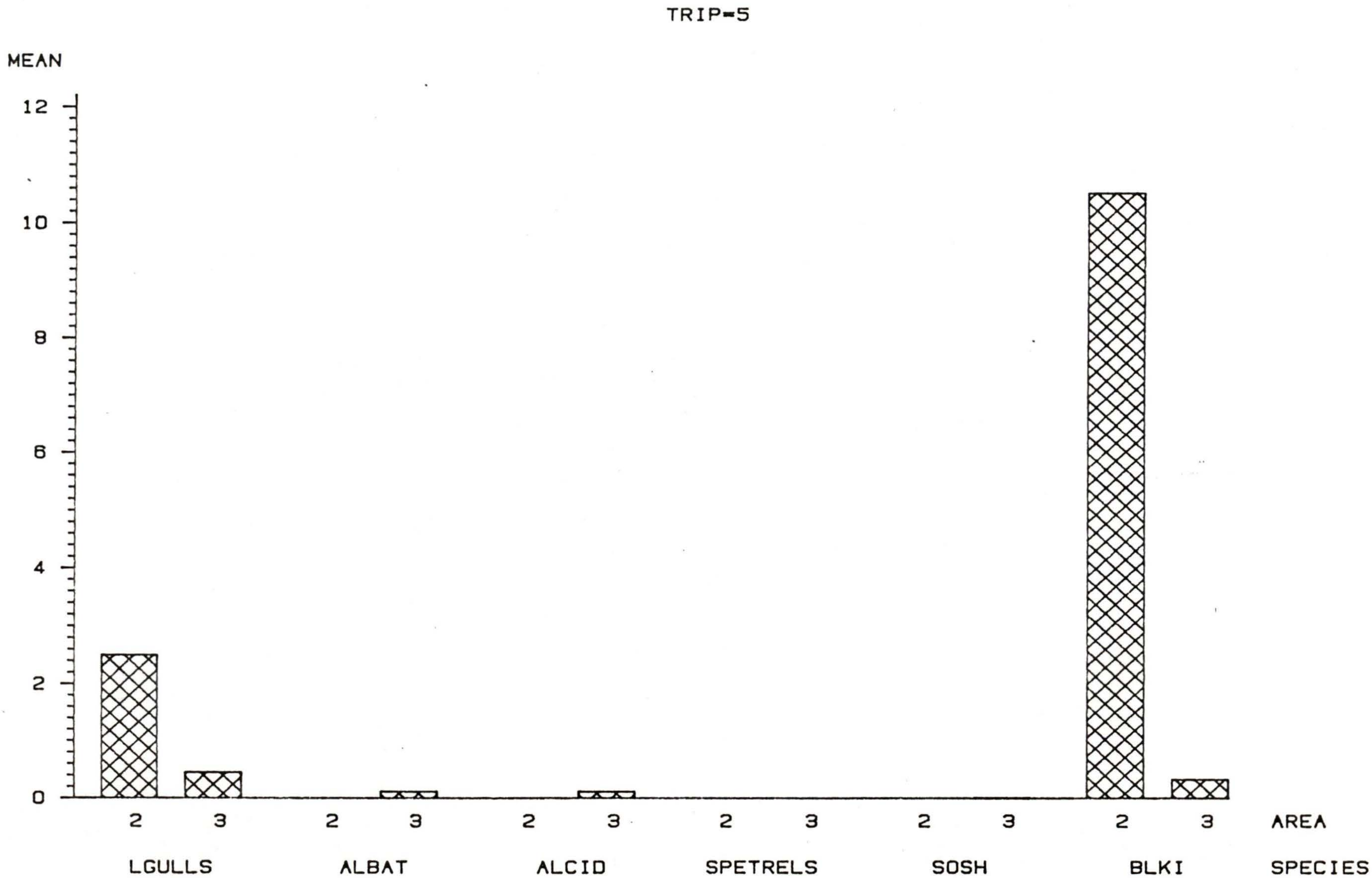

Figure 17: Bar graphs of mean species counts per 10 minute observation, in areas ranked by increasing offshoreness (3=farthest offshore). Trip 5

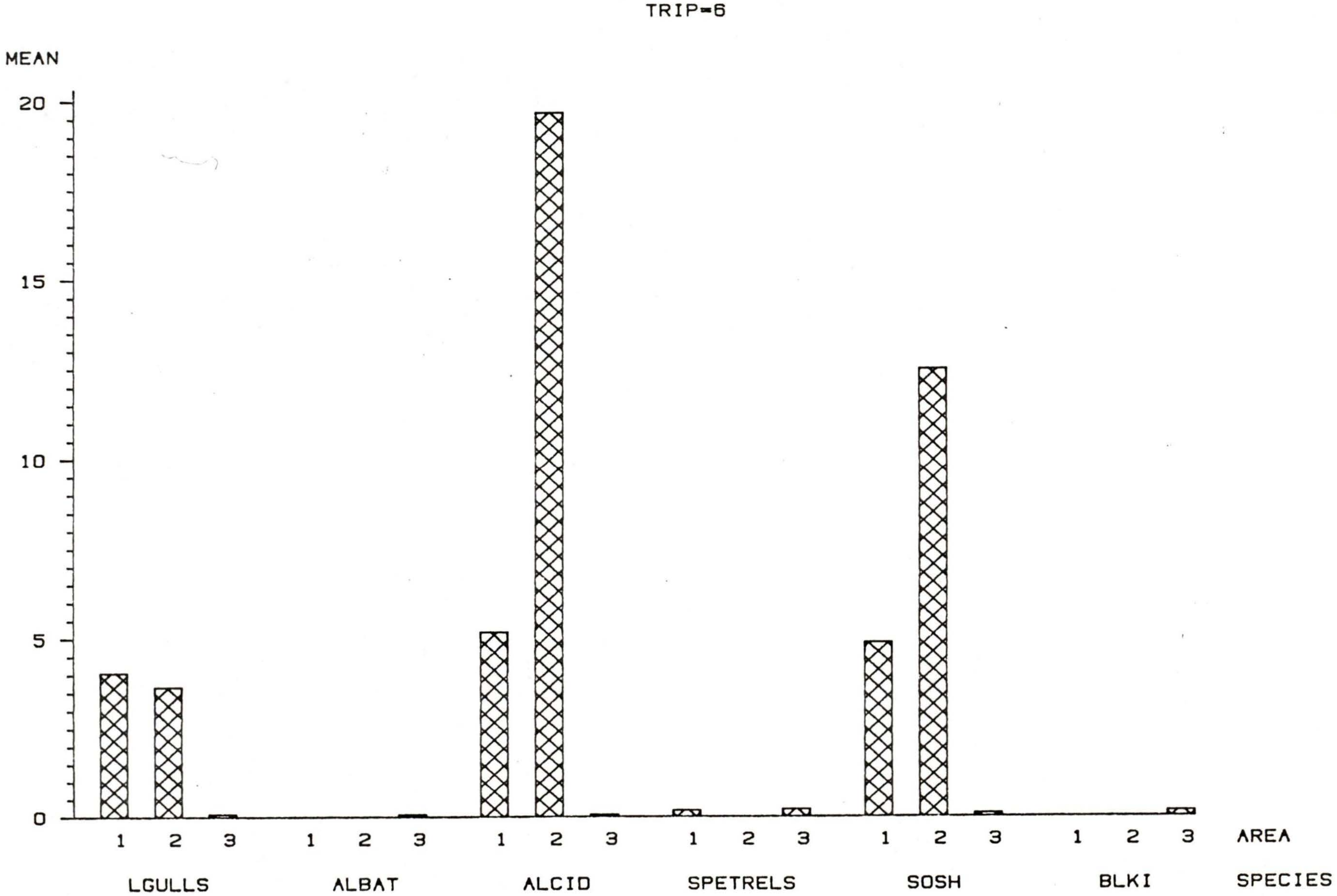

Figure 18: Bar graphs of mean species counts per 10 minutes, in areas ranked by distance offshore (3=farthest offshore). Trip 6

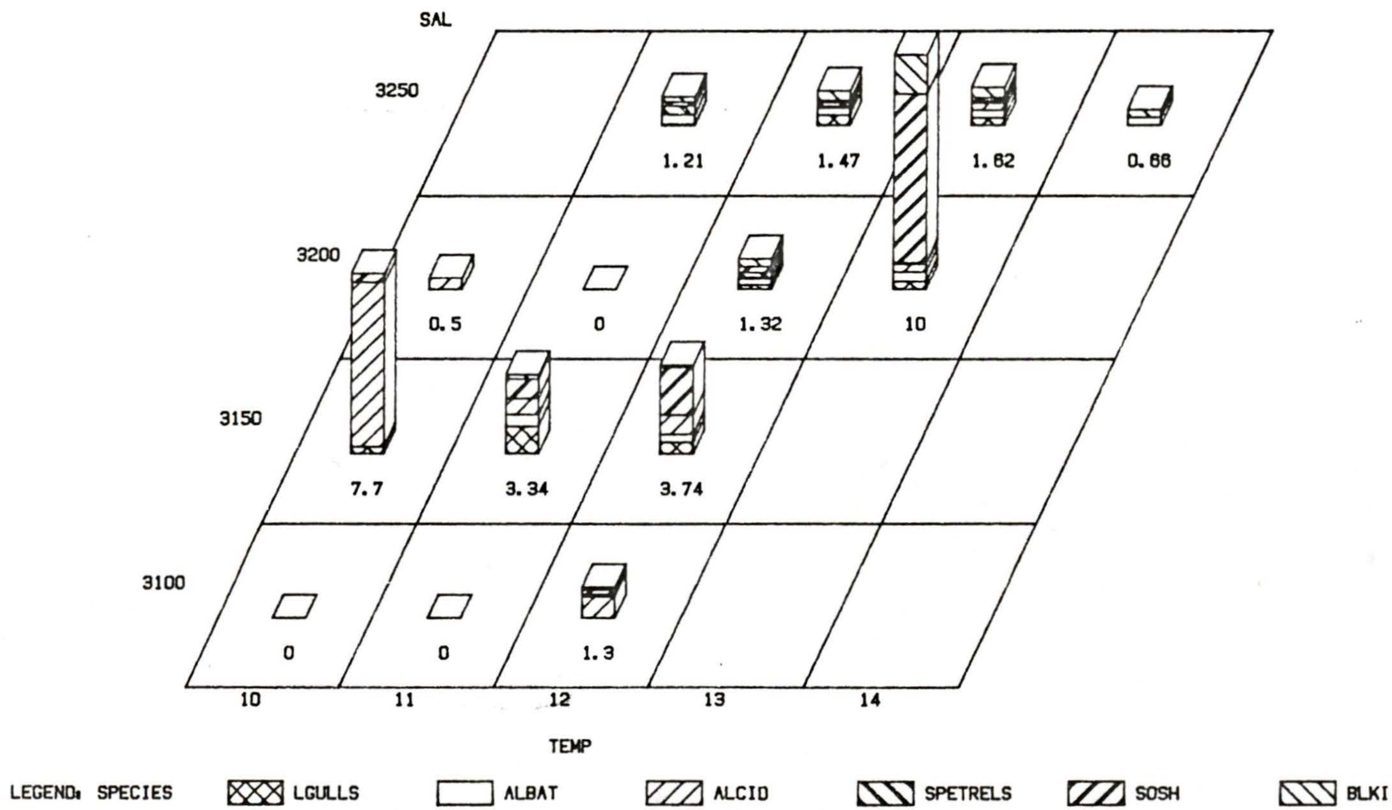

Figure 19: Block chart of mean species counts per 10 minutes, in sal/temp cells. Sums of the six species means are below bars. Trip 1

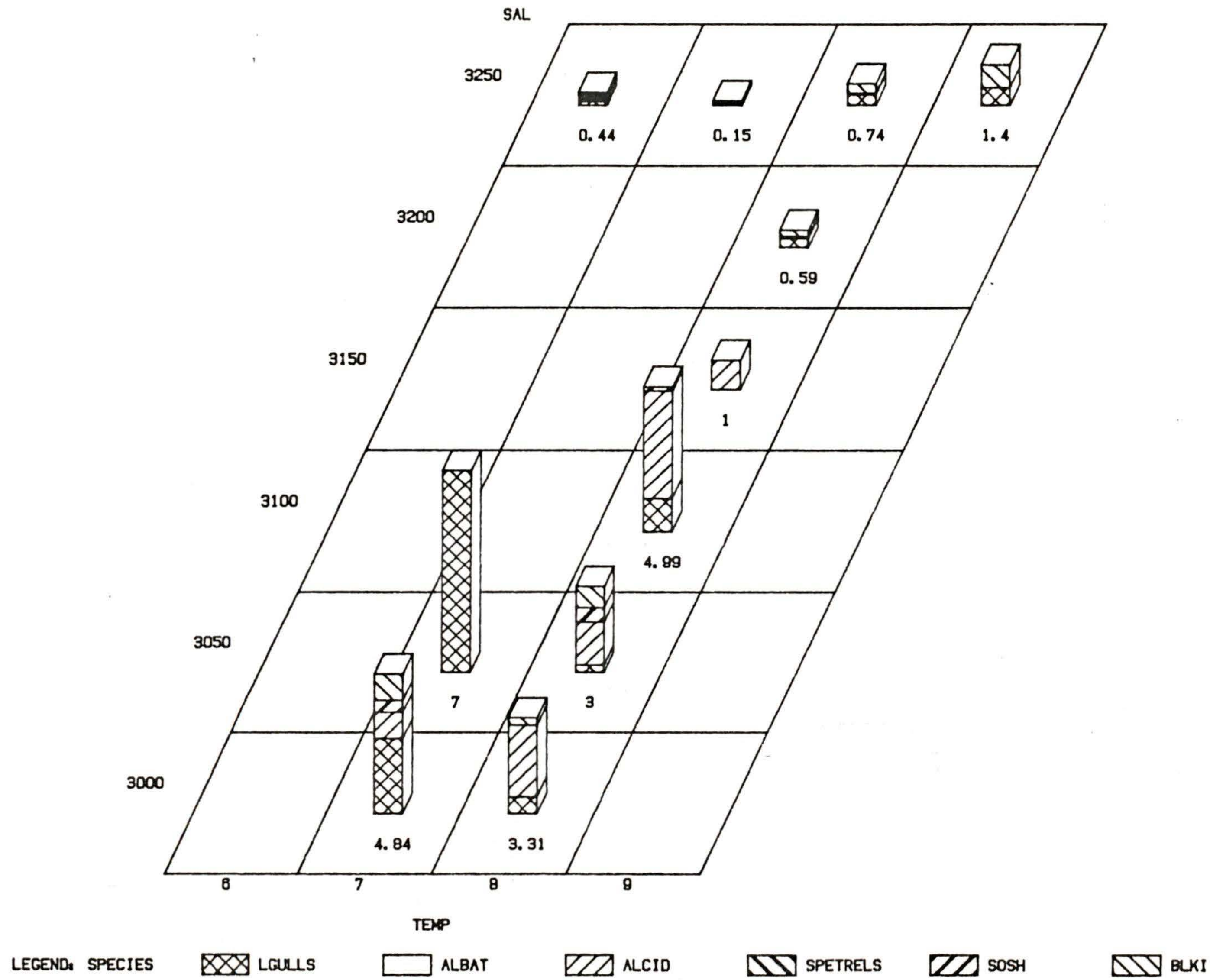

Figure 20: Block chart of mean species counts per 10 minutes, in sal/temp cells. Sums of the six species means are below bars. Trip 2

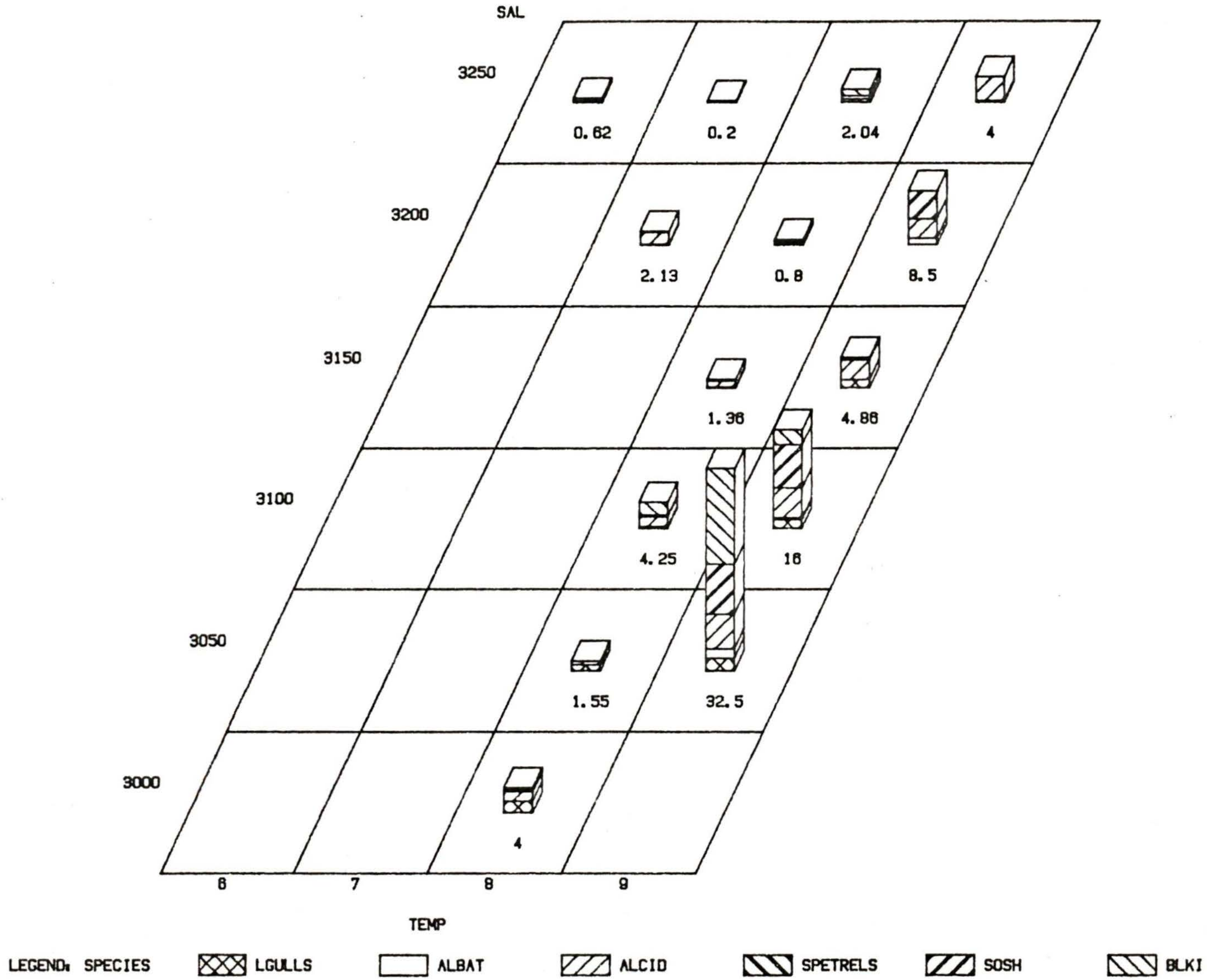

Figure 21: Block chart of mean species counts per 10 minutes, in sal/temp cells. Sums of the six species means are below bars. Trip 3

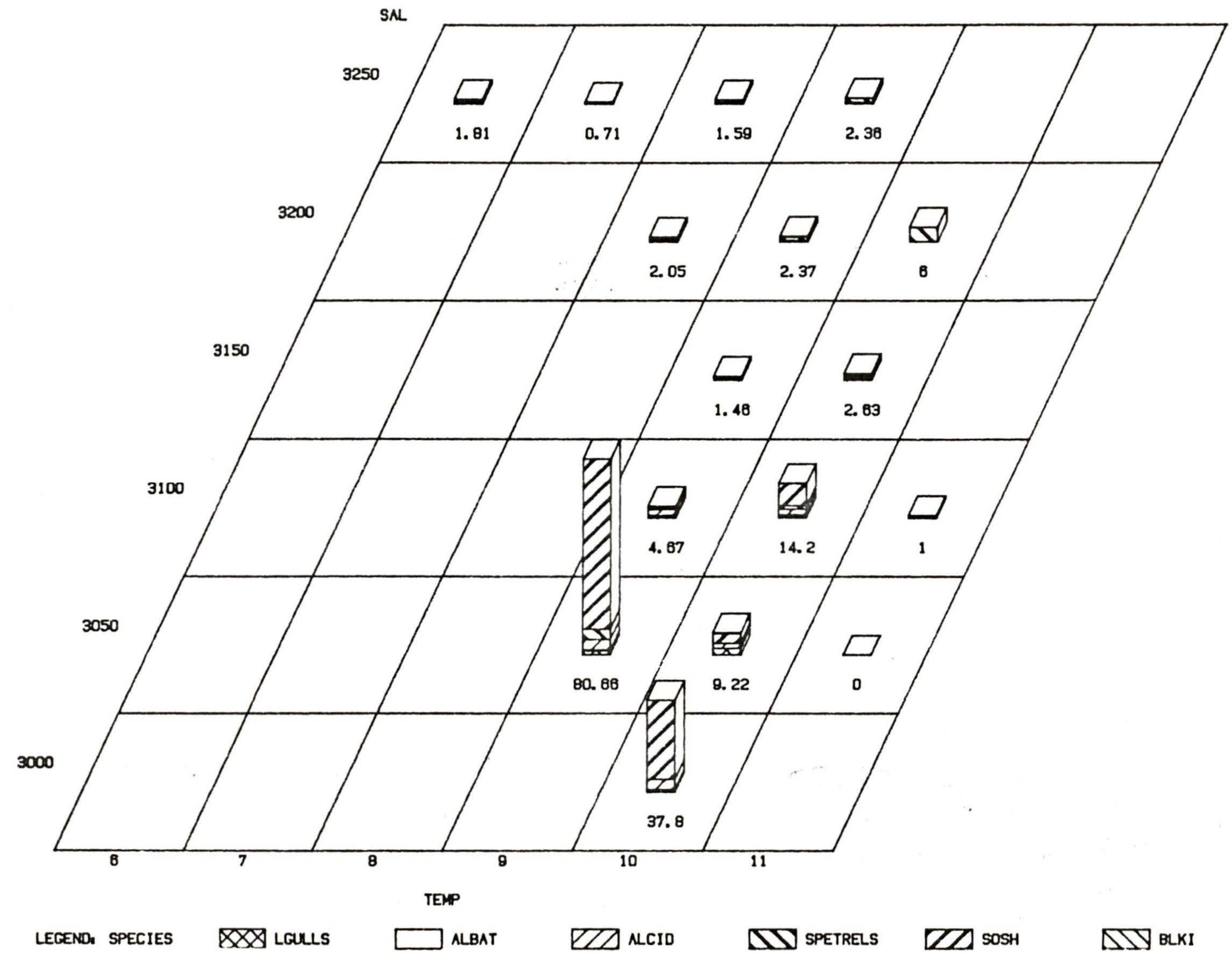

Figure 22: Block chart of mean species counts per 10 minutes, in sal/temp cells. Sums of the six species means are below bars. Trip 4

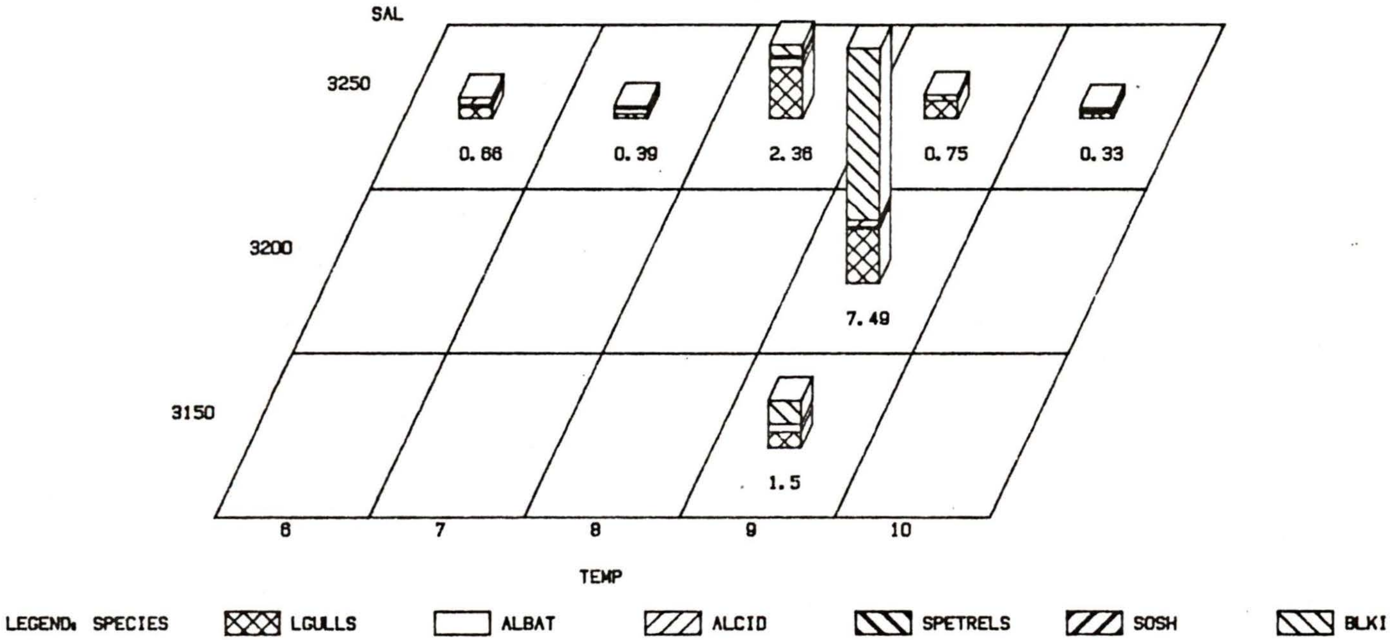

Figure 23: Block chart of mean species counts per 10 minutes, in sal/temp cells. Sums of the six species means are below bars. Trip 5

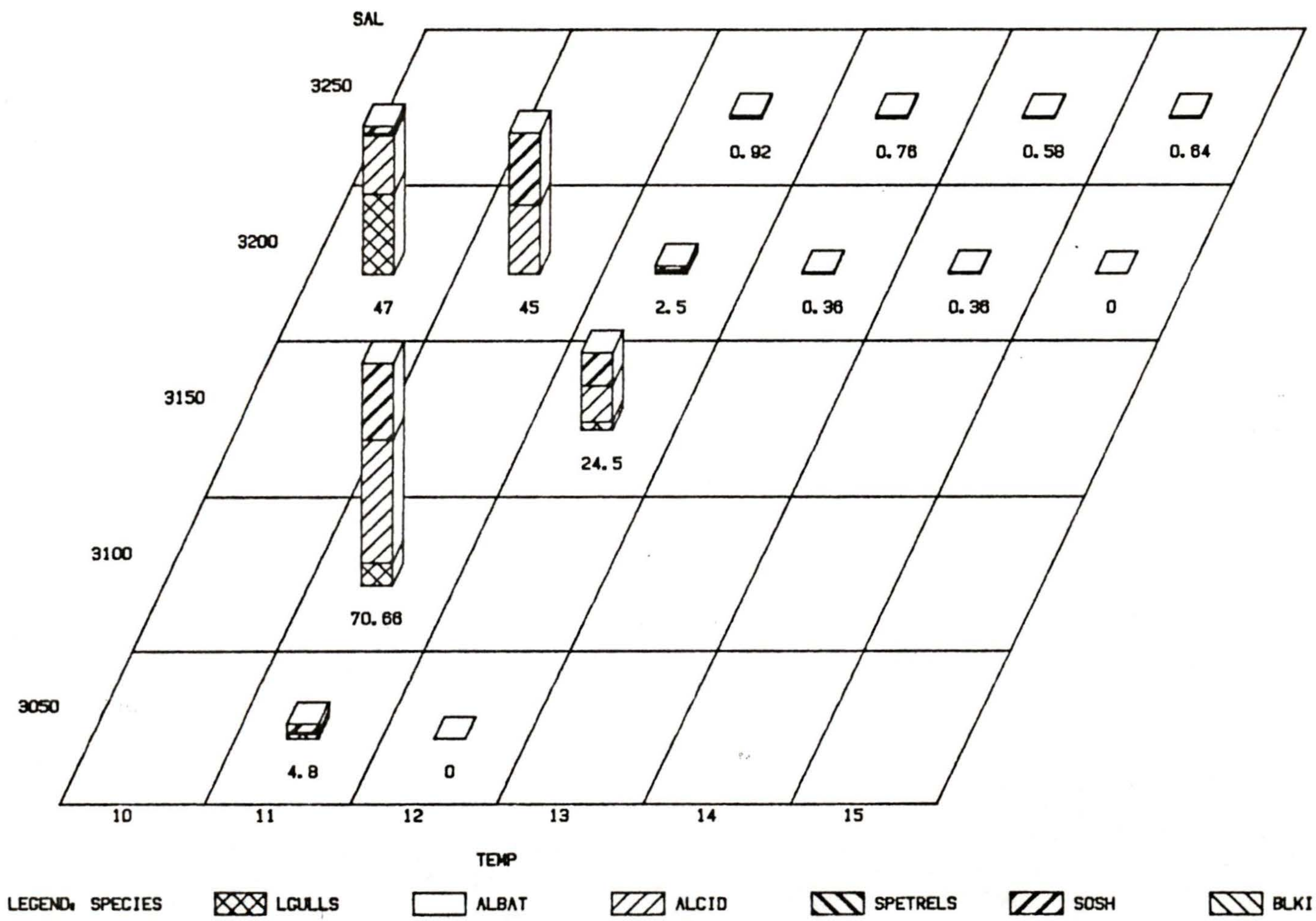

Figure 24: Block chart of mean species counts per 10 minutes, in sal/temp cells. Sums of the six species means are below bars. Trip 6

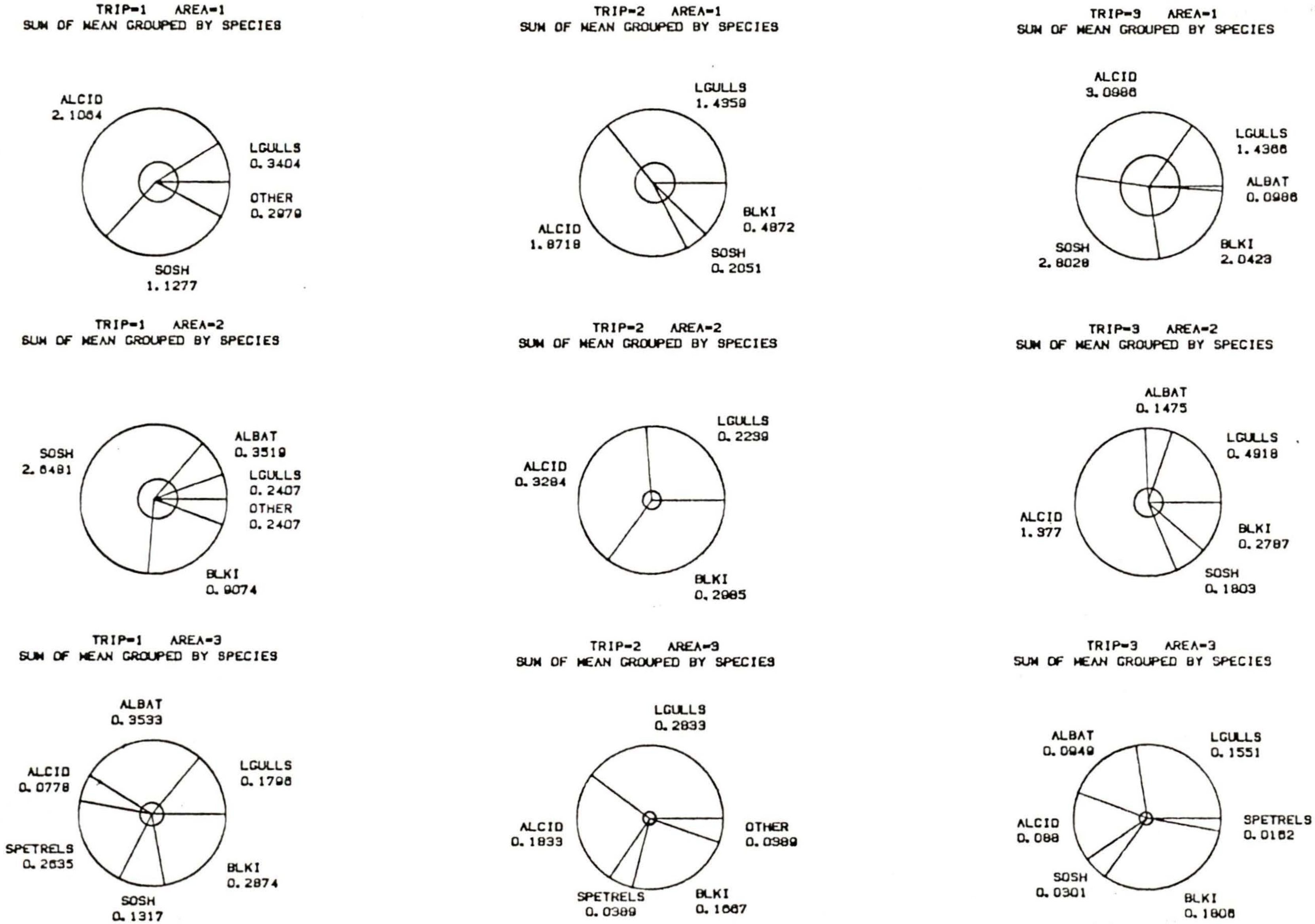

Figure 25: Pie charts showing mean species counts per 10 minute observation, by trip and area; pie fractions indicate species' contribution relative to total per observation; log[diameter] of inner circle is proportional to mean total per observation for comparison of trip/area cases.

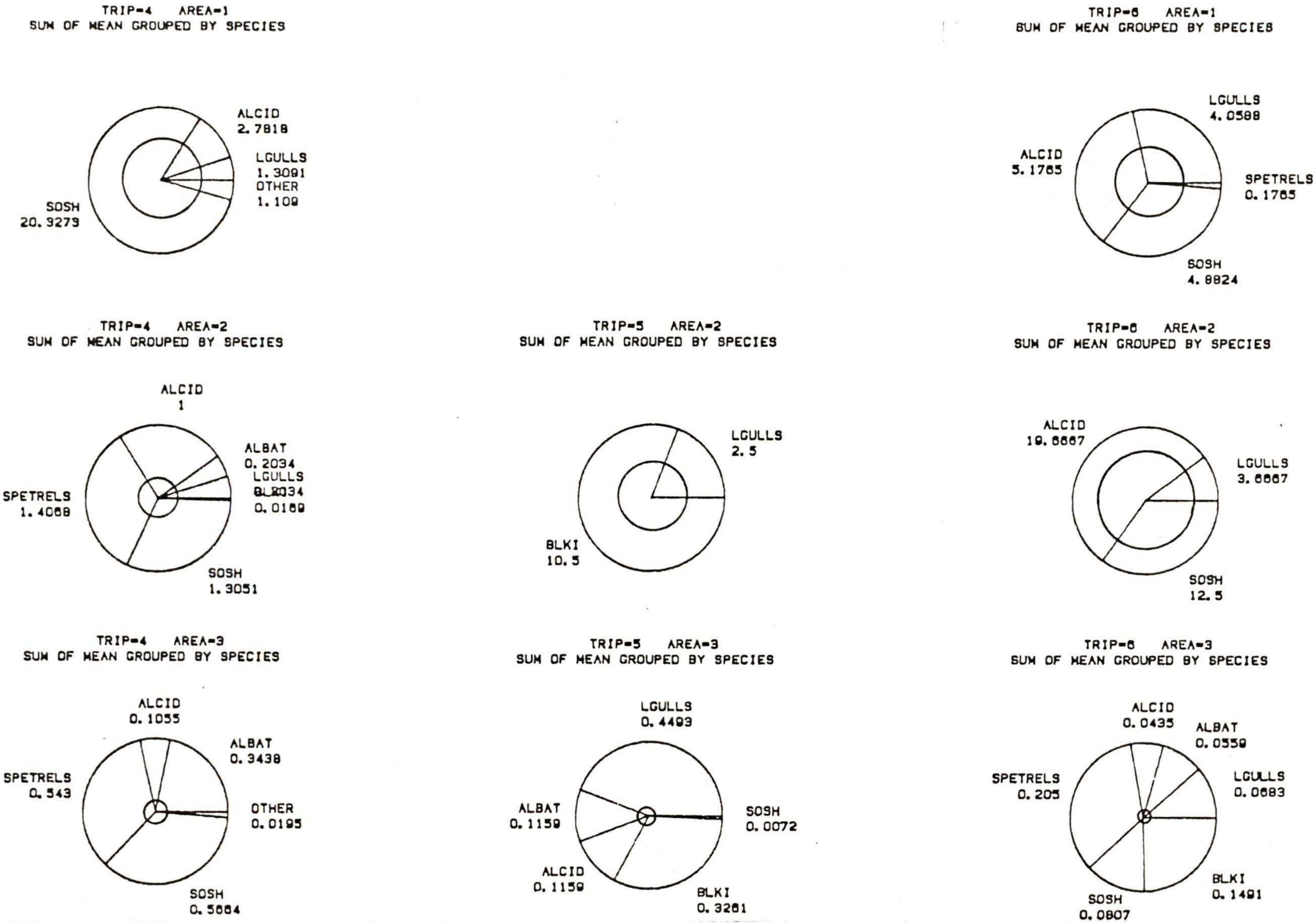

Figure 25 continued: Pie charts showing mean species counts per 10 minute observation, by trip and area; pie fractions indicate species' contribution relative to total per observation; log[diameter] of inner circle is proportional to mean total per observation for comparison of trip/area cases.

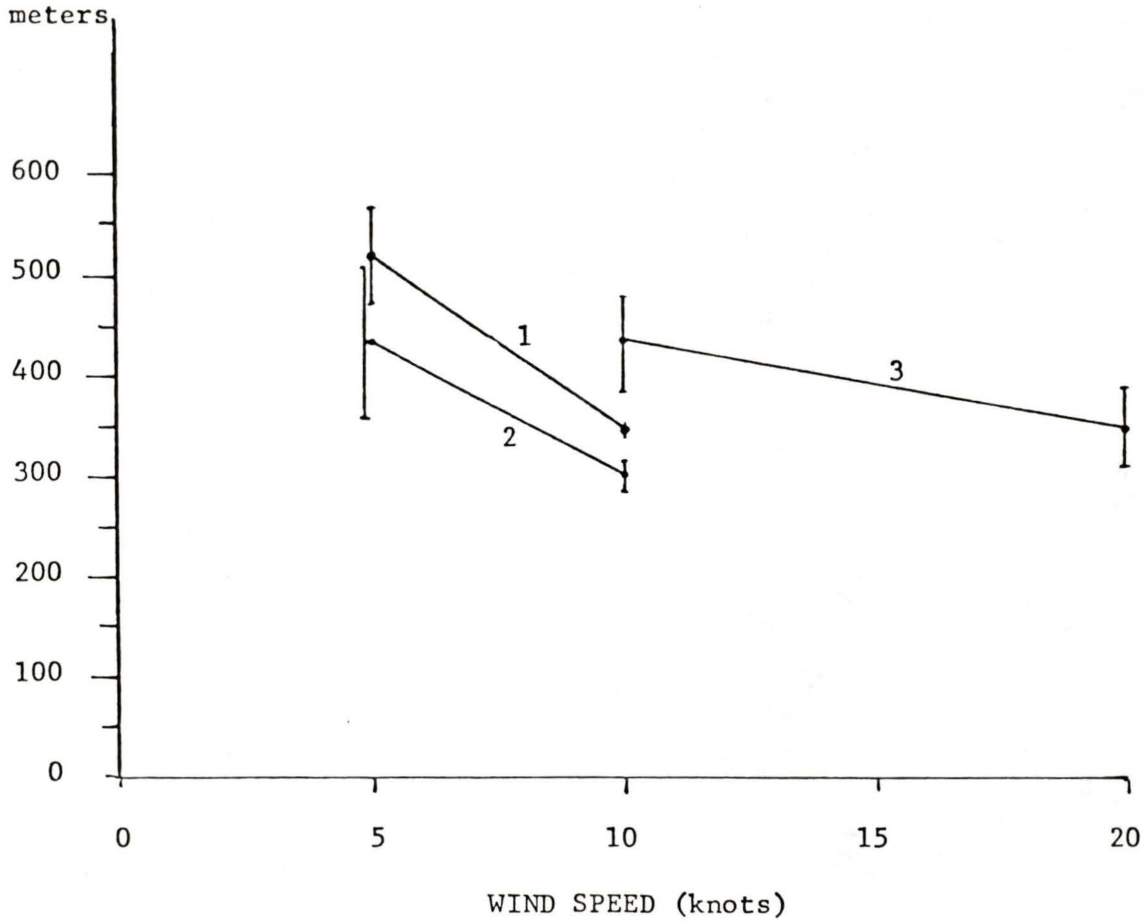

Figure 26: Effect of wind speed on visibility of small objects (balloons) on the sea surface. Average visibility distances (.) plus or minus one standard deviation (I) for three combinations of target balloon diameter and observer height are plotted at different wind speeds. Each pair of points is joined by a line which indicates pair identification only. The overall trend is that visibility decreases rapidly for smaller objects (case 1 & 2), observed at relatively light winds, while larger objects (case 3) slowly diminish in visibility as wind increases.

Case 1: diameter = 10cm, observer elevation = 9m.
Case 2: diameter = 10cm, observer elevation = 3.5m.

Case 3: diameter = 16cm, observer elevation = 9m.

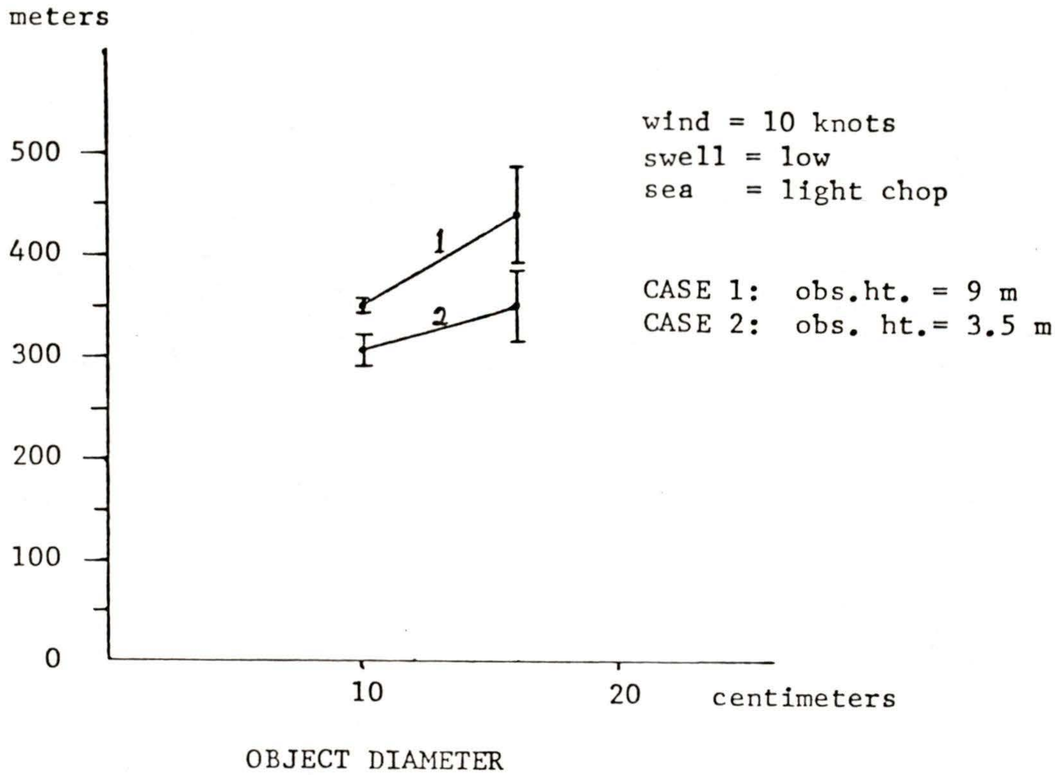

Figure 27: Effects of object diameter on visibility of small objects (balloons) on the sea surface, under constant wind, swell and sea conditions. As object diameter increases visibility increases. The effect is most apparent at the higher observer position (Case 1).

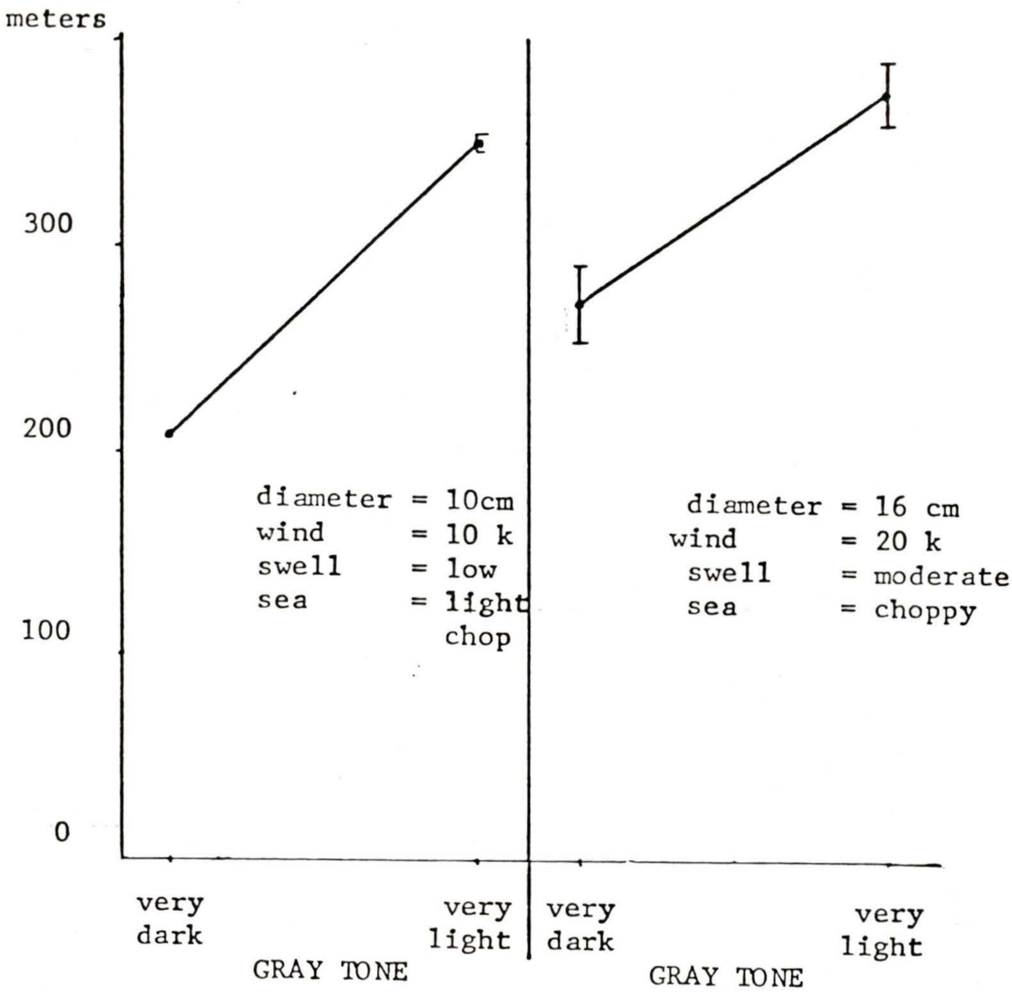

Figure 28: Effects of gray tone on visibility of small objects (balloons) on the sea surface, with constant conditions of size, observer elevation, wind, swell and sea. Two extremes of tone (near black and pale yellow) were used. The light toned balloons were always more visible (up to 1.7 times) than the dark ones under the same set of conditions.

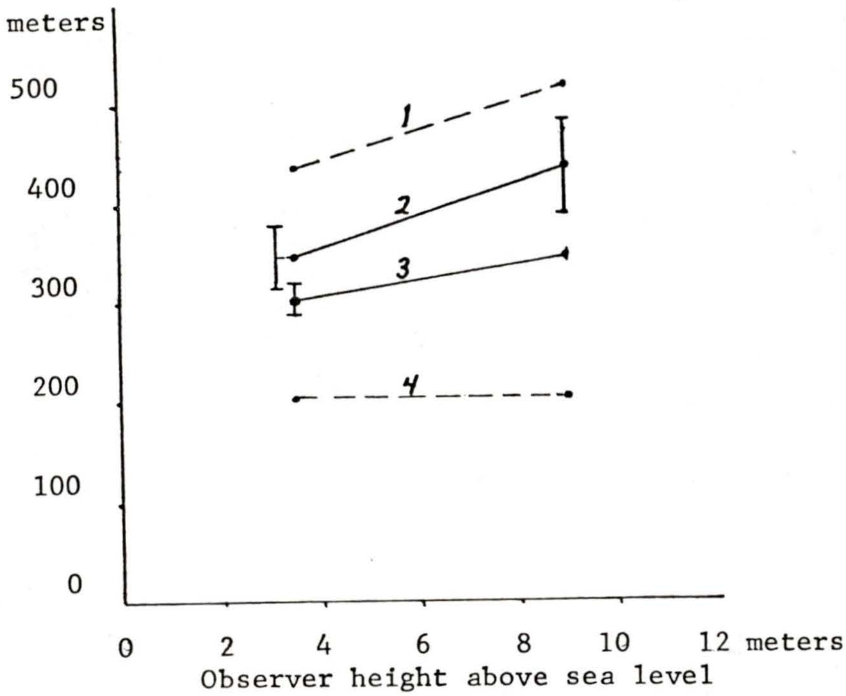

Figure 29: Effect of observer height above sea level on visibility of small objects (balloons) on the sea surface. Lines 2 and 3 bracket the range of mean visibility distances observed using 16 cm (line 2) and 10 cm (line 3) balloons under constant conditions of gray tone, wind, swell and sea state. Plus or minus one standard deviation about the mean values are indicated. The lower limit was observed for small black balloons during the same conditions. It actually decreases slightly with observer height (from 216 to 212 m). The upper limit (line 1) occurred during a lower wind speed and suggests that for light toned objects visibility increases as wind and sea approach calm conditions.

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