ANNUAL REPORT

RU # 108

October 1977 - March 1978

SIMULATION MODELING OF MARINE BIRD POPULATION ENERGETIC, FOOD CONSUMPTION, AND SENSITIVITY TO PERTURBATION

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Submitted 31 March 1978

1. SUMMARY

This report presents the approach and results of initial applications of computer simulation modeling of avian population energetic to Alaskan OCS marine bird systems. As such, it meets some of the overall objectives of this Research Unit, namely: 1) to use simulation model analyses to estimate the energy demands and food consumption patterns of marine bird populations in -the Bering Sea, emphasizing the dynamics of the Pribilof Islands colonies; 2) to develop new model structures to evaluate the spatial distribution of avian energetic; 3) to use the models as gaming tools to simulate the influences of variations in baseline conditions on the populations and their energetic; and 4) to define the feasibility of using the modeling approach as a means of synthesizing information gathered at breeding colonies by different investigators in the OCSEAP studies. The present report considers estimations of energy demands of marine birds as recorded at sea during transect censuses in the Gulf of Alaska/southeast Bering Sea and in the vicinity of the Pribilof Islands; more intensive analyses of breeding colonied will occupy the next phase of the project.

Total energy flow through pelagic bird populations in the Gulf of Alaska was greatest in the Kodiak area during August-September (24,300 kcal km^{-2} day-l), but varied both between areas and with season, primarily as a consequence of movements of species populations associated with reproductive status. Shearwaters were usually the dominant species, energetically, in these systems, accounting for up to 92% of the total community energy demand. In the Pribilof Islands, total community energy demand was concentrated in the area about St. George, largely as a result of the major contribution of murres to community energetic. There also eneregy demands varied both with season and year, and different species populations exhibited different spatial patterns of energy demands in relation to distances from islands and depth of water, -especially in relation to the continental shelf break. The area about St. George is obviously quite important in terms of overall avian energy demands, and some other foci of apparent feeding concentration may also be critical. Activities related to petroleum development in these areas may be especially hazardous to bird populations. The distribution of birds in the region of the shelf break to the southwest of St. George is poorly known, and should receive special attention in future transect census work.

11. INTRODUCTION

There are several ways in which one may view the structure and functioning of ecosystems: through energy fluxes, nutrient flows and cycles, biotic feedback controls, or systems sensitivity to abiotic driving variables, to name but a few. In marine ecosystems, bird populations act as primary and secondary consumers; while their dynamics may be interpreted in all of these dimensions, consideration of energy flows is perhaps most appropriate. Birds are closely linked to other systems components through feeding webs, and while ultimately these trophic relationships should be expressed as detailed estimates of the quantities of material (or individuals) taken from each prey source by specific bird populations, an initial approach may involve documentation of the energy fluxes into the bird populations alone. Such a consideration of energetic may provide a means to assess the magnitudes of utilization of various oceanic areas for feeding, or to evaluate the relative "importance" of various bird species in exploiting marine productivity.

The long-range goals of this research unit are to define a number of ways of exploring the energetic linkages of marine birds to their ecosystems, in both space and time; to provide a means of using this approach to synthesize data gathered in diverse OCSEAP marine bird investigations within a common framework; and to offer some initial estimations of the potential impacts of marine birds on marine systems, and of various petroleum-related perturbations upon the bird populations and communities. As energy demands are impossible to measure directly under field conditions, our approach rests heavily upon computer simulation modeling. In this first report of these research efforts, we describe the initial applications of energetic modeling to the estimation of energy demands of marine bird assemblages as recorded during shipboard census transects in the Gulf of Alaska and Bering Sea. Later efforts will be devoted to more intensive evaluations of the time/space patterns of energy flow into breeding seabird colonies.

III. METHODS

Model Structure--- The initial modeling approach utilizes a computer simulation model (BIRD II) that estimates changes in population sizes and composition and their energy demands on a daily basis. The details of the model structure, assumptions, and applications are given in several publications (Wiens and Innis 1973, 1974; Innis et al. 1974; Innis and Wiens 1977; Wiens and Scott 1975; Wiens and Nussbaum 1975; Wiens 1977; Wiens and Dyer 1977) and will not be repeated here. Still, some background *is* essential.

The model contains three basic portions. In one, information on population size at various times, on reproductive biology and timing, and on mortality is used to project daily estimates of the population size of each age class of each of up to 15 species. Another generates estimates of individual, age class, population, and "community" energy demands from a series of metabolic functions. A third portion combines the daily energy demand estimates with information on dietary composition to project the daily consumption rates of various prey categories by the birds.

The data sets to be considered in this report contained only information on densities of birds at sea in various areas at defined points in time. Therefore, neither the population dynamics (reproduction) nor the dietary composition portions of the model were really employed in these analyses. The energetic calculations of the model were founded upon the equations presented by Kendeigh et al. (1977) for non-passerines. These relations project existence metabolic energy requirements (Kcal $bird^{-1}$ day^{-1}) (M) from information on body weight (W, in g), as functions of ambient temperature and photoperiod:

10-h photoperiod, 30°C: $M = 1.455\ W^{0.626}$

10-h photoperiod, 0°C: $M = 4.235\ W^{0.532}$

15-h photoperiod, 30°C: $M = 1.068\ W^{0.664}$

15-h photoperiod, 0°C:. $M = 4.142\ W^{0.544}$

These existence energy requirement estimates are then adjusted to consider the additional costs of free-living activity, and the final metabolic demand is then adjusted to reflect the inefficiency of the digestive process to project a final estimate of the energy demand actually required of the resource base exploited by the birds. As the analyses we considered here were confined to short time periods, all during late spring through early fall, the calculations were simplified by considering energy demands at an ''average" photoperiod of 12 h for all analyses, and by arbitrarily assigning an additional cost of free-living activity of 0.2 times existence metabolism, rather than allowing this cost to vary as a function of season and reproductive status. The final estimates we report are thus derived from simplified model analyses and, in that they do not consider reproductive activities, growth, molt, or other aspects of seasonality, the values are conservative estimates.

The Data Base--- We have conducted preliminary analyses of two series of seabird density estimates derived from shipboard transects conducted in the Gulf of Alaska/southeast Bering Sea and in the vicinity of the Pribilof Islands.

A. Gulf of Alaska/Bering Sea: Transects conducted from August 1975 to November 1976 provided estimates of the densities of marine bird species in five defined areas of the Gulf of Alaska and Bering Sea; the transect methods, ship tracklines, and census results are fully described by Wiens, Heinemann, and Hoffman (1977, 1978) and will not be further described here. For our model analyses, the population densities reported for the 13 time-area units were used directly as initially reported. In the earlier census reports, however, densities of shearwaters and of large gulls were reported for combined species, with an estimate of the abundance ratio of the component species also given. For this analysis, densities of separate shearwater species and large gull species were derived by converting the total combined density using the ratio estimate. These densities, multiplied by the per individual energy demands. calculated from the BIRD 11 simulations, provided an estimated daily energy demand per km2 for each species population in each area-time unit,

B. Pribilof Islands: Our more detailed analyses of at-sea energy demands of birds about St. Paul and St. George utilized the data gathered during transect censuses by Hunt and his colleagues. As the initial reports of these censuses were only summaries (Hunt 1976, 1977), we obtained the original census results for each transect directly from Hunt's laboratory. Mean densities (weighted according to total transect length censused) were calculated for each 10' X 10' latitude-longitude block in the survey area. These densities were then converted into energy flow estimates, using the model procedures outlined above.

IV. RESULTS

Gulf of Alaska/southeast Bering Sea--- The transects conducted by our group in these areas yielded the density estimates summarized in Table 1; the areas for which individual transects were combined are shown in Fig. 1. The energy flow values estimated for these populations are given in Table 2, with the percentage contribution of each of these species to the total marine bird "community" energy flow. These data are summarized in Fig. 2. This analysis ignores various species recorded only incidentally in transect censuses, and thus although all major species are included, the total "community" is somewhat incomplete.

Several features of these data merit comment. Many of the changes in the relative contributions of species to energy flow are of course related to their seasonal movements into and out of breeding areas (see Wiens et al. 1977, 1978). The increase in total energy demand by the marine bird assemblage in the NEGOA between April and May (Fig. 2), for example, represents an influx of birds into the region to initiate breeding, as is also the case in the Kodiak area. As in the Oregon coastal marine bird communities analyzed by Wiens and Scott (1975), shearwaters were usually the dominant species in the energetic of these Alaskan bird systems, accounting for up to 92% of the total energy flow (Kodiak, August-September; Table 2). Shearwaters made minor contributions to community energetic in the Cook Inlet area in May, and were not recorded in transects in the Bering area in June (Table 1). Gulls and kittiwakes contributed importantly to community energetic only in the Kodiak area during June, chiefly as a consequence of large aggregations of Black-legged Kittiwakes in this area at this time. Energy flow through large alcid populations (murres and puffins) was substantial only in the NWGOA and Bering areas, especially during June.

Total community energy demand for these pelagic bird assemblages varied both with time and area, being least in the Kodiak area in April and greatest in the same area in August-September (Table 2, Fig. 2). Bear in mind that the values we report are estimates of *daily* energy demand per km^2. Compared with some other ecosystem types the peak daily energy flow through these bird assemblages is not especially large: Wiens (1977) reported a peak flow of 19,000 kcal km^{-2} day^{-1} in grassland bird communities, Wiens and Scott (1975) a value of roughly 54,000 kcal km^{-2} day^{-1} for a four-species community of Oregon seabirds during the breeding season, and Wiens and Nussbaum (1975) a peak demand of 150,000 kcal km^{-2} day^{-1} for breeding birds in northwestern mesic coniferous forests. These values were for stationary and concentrated breeding populations, however. In Alaskan waters, peak

Table 1. Estimated densities (individuals km^{-2}) of bird populations in five Alaskan OCS lease areas (see Fig. 1). * = densities not calculated; no ratio available.

Species[a]	NEGOA[b]		KODIAK					COOK INLET		NWGOA[b]		BERING	
	April	May	April	May	June	Aug-Sept	Ott	May	Aug	June	Aug	June	Aug
N (transects)	49	26	9	8	5	23	14	6	13	8	5	12	8
Northern Fulmar	0.06	0.14	0.03	0.05	0.81	0.64	0.96	0	0.02	2.84	1.36	1.79	0.01
Sooty Shearwaters	1.14	4.96	0	7.86	3.32	85.94	0.02	*	5.30	0.11	0.02	0	0.10
Short-tailed Shearwaters	4.45	7.73	0.05	0.16	8.46	1.65	9.03	*	o	72.44	18.63	0	4.65
Fork-tailed Storm-petrel	O	1.73	0	1.54	1.27	6.45	1.10	0	0.02	15.92	1.25	6.18	1.43
Herring Gull	0.41	0.04	0.07	0.04	0	0.02	*	o	0	0	0	0	0
Glaucous-winged Gull	0.64	0.03	0.57	0.30	0.06	0.08	*	2.31	0.01	0.03	0	0	0
Black-legged Kittiwake	0.37	0.85	0	10.66	0.27	1.21	*	0.41	2.62	0.05	0	0.66	0.42
Arctic Tern	0.01	0.26	0	0.51	0	0.26	0	0	0.06	0	0	0	0
Common Murre	0.20	0.06	0.39	0.44	0.02	0.20	0.04	0.32	0.72	0.39	0.03	1.05	0.43
Thick-billed Murre	o	0	0	0	0	0	0	0	0	0.27	O	4.56	0.67
Tufted Puffin	0.99	0.09	0.04	7.25	0.09	3.56	2.33	0.07	2.30	8.85	0.97	0.42	0.86
Horned Puffin	0.01	0.01	0	0	0.05	0.07	2.82	0	1.61	0.80	0.17	0.81	0.08

[a]Scientific names are given in Appendix I.

[b]NEGOA = Northeastern Gulf of Alaska; NWGOA = Northwestern Gulf of Alaska

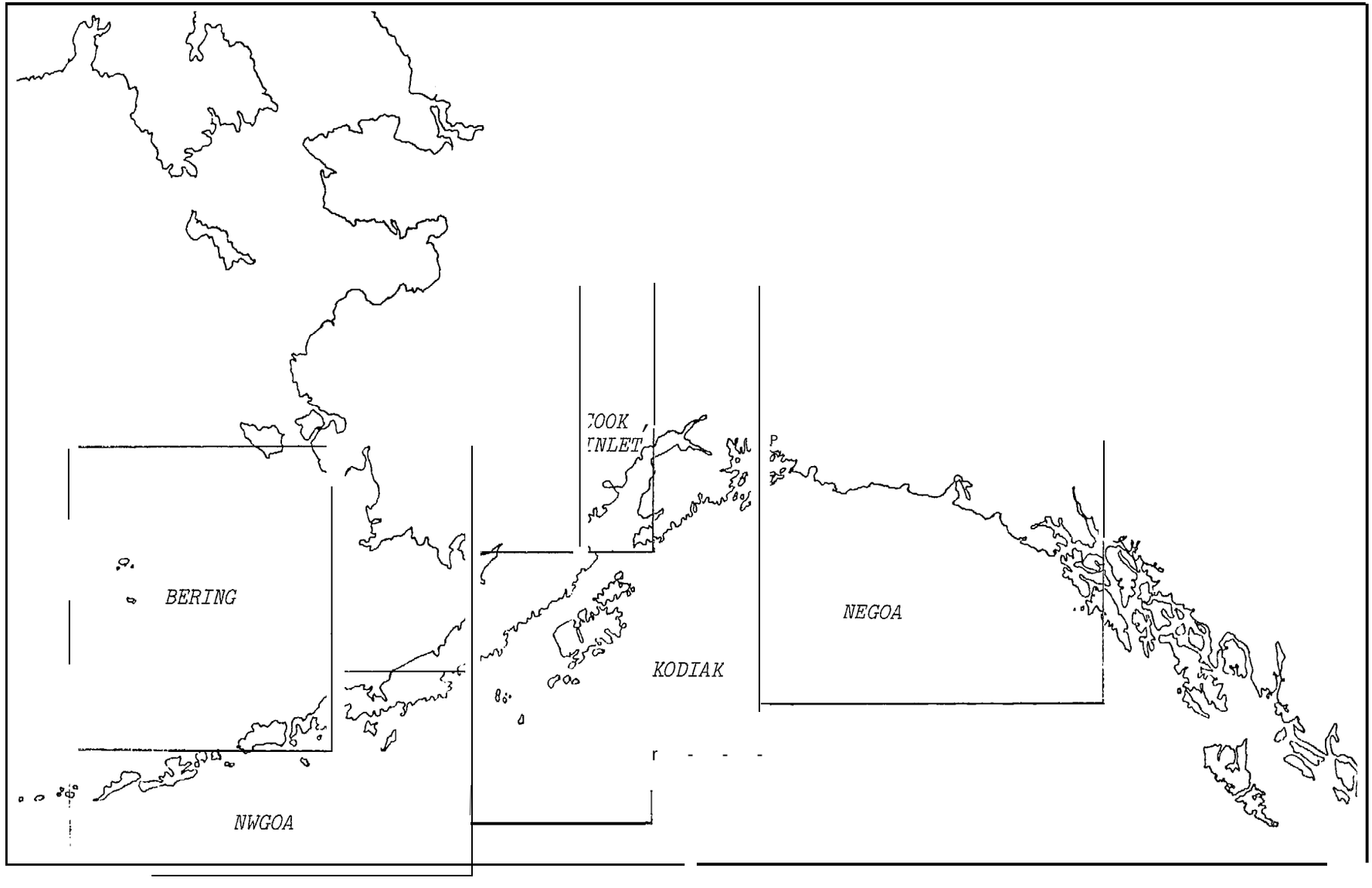

Fig. 1. Areas of the Gulf of Alaska/southeast Bering Sea used to summarize marine bird transect census results,

Table 2. Estimated energy demands (kcal km-z day^{-1}) of bird populations in five Alaskan OCS lease areas. Values in italics are percentages of the total energy flow for a lease area at that time.

Species	NEGOA[a]		KODIAK					COOK INLET		NWGOA[a]		BERING	
	April	May	April	May	June	Aug-Sept	Ott	May	Aug	June	Aug	June	Aug
Northern Fulmar	16	37	8	13	212	168	252		5	745	357	469	3
	1	*1*	2	*t*	*7*	*1*	7		*t*	4	8	16	*t*
Sooty Shearwater	295	1,280		2,030	859	*22,200*	6		1,370	29	6		26
	15	39		32	28	*91*	*t*		*45*	*t*	*t*		2
Short-tailed Shearwater	938	1,630	11	34	1,780	348	*1,910*			15,300	*3,930*		981
	47	50	3	*1*	58	1	*55*			78	*84*		56
Fork-tailed Storm-petrel		96		86	71	358	*62*		1	884	*70*	343	80
		3		*1*	2	*1*	*2*		*t*	5	*1*	12	5
Herring Gull	124	12	21	12		6							
	6	*t*	6	*t*		*t*							
Glaucous-winged Gull	216	*10*	193	101	20	27		781	3	10			–
	11	*t*	54	2	*1*	t		80	t	*t*			
Black-legged Kittiwake	*70*	162		2,030	51	230		78	499	10		126	80
	4	5		32	2	*1*		8	16	t		4	5
Arctic Tern	t	23		45	23			5					
	t	1		*1*	*1*			*1*					
Common Murre	57	17	112	126	6	57	12	92	206	112	9	301	123
	3	1	32	2	*t*	*t*	*t*	9	7	*1*	*t*	*10*	7
Thick-billed Murre			–							86		1,390	205
										t		48	12
Tufted Puffin	260	24	11	1,900	24	934	612	18	604	2,320	255	110	226
	13	t	3	30	*1*	4	18	2	20	12	6	4	13
Horned Puffin	2	2			11	15	610		348	173	37	175	17
	t	t			*t*	*t*	*18*		12	1	*1*	6	*1*
TOTAL	1,980	3,290	355	6,380	3,060	24,300	3,460	974	*3,040*	19,700	4,660	2,910	1,740

[a]NEGOA = Northeastern Gulf of Alaska; NWGOA - Northwestern Gulf of Alaska.

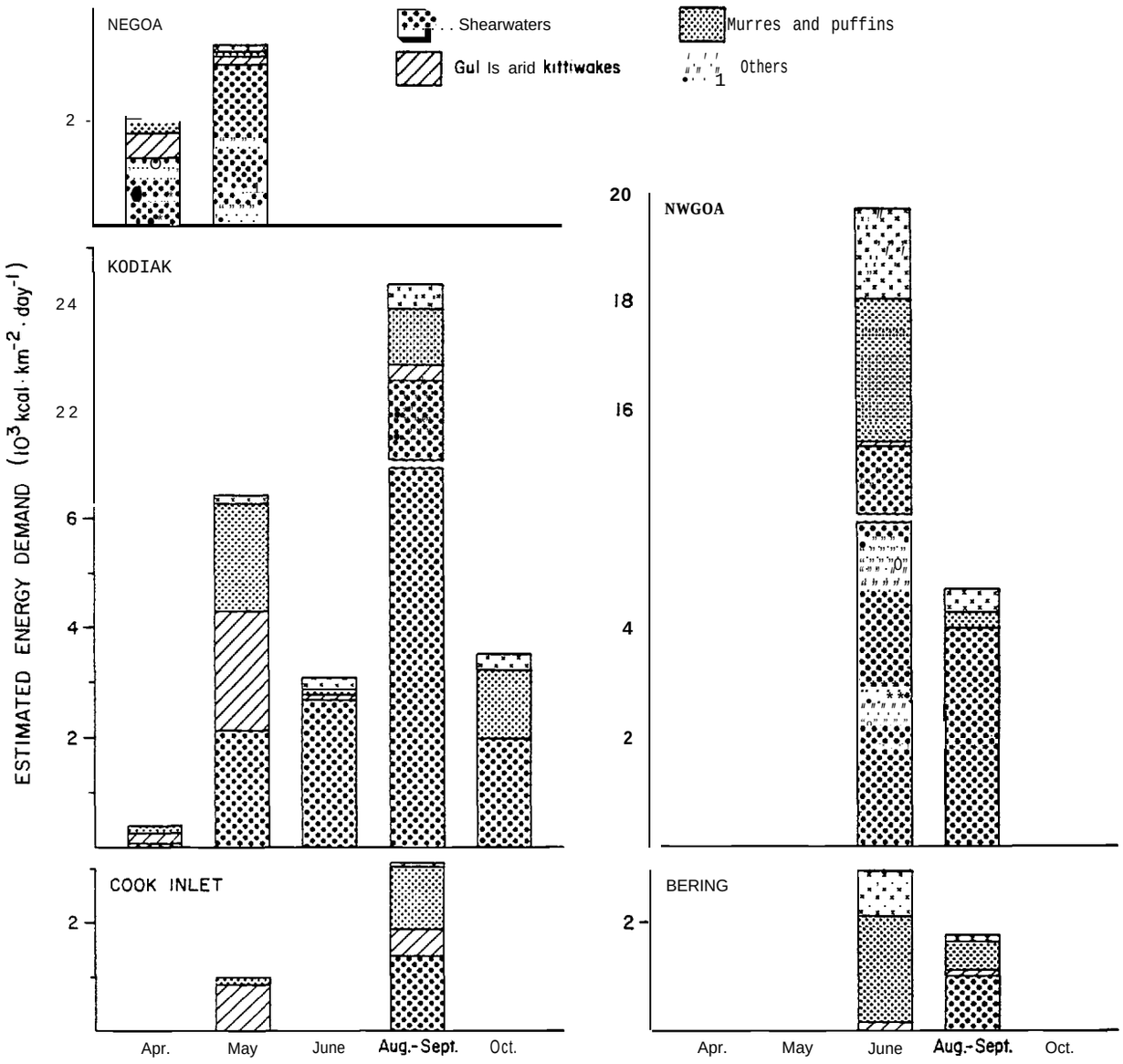

Fig. 2. Apportionment of total energy demand among the species groups recorded during transect censuses in five areas of the Gulf of Alaska/southeast Bering Sea, according to time of censusing.

energy demands are undoubtedly greater in the vicinity of breeding aggregations, and of course the total population sizes over the ocean expanses in the Gulf of Alaska are much larger than those of the terrestrial passerine in more restricted habitat types.

Pribilof Islands --- The censuses conducted by George Hunt and his colleagues in the vicinity of the Pribilof Islands during 1975-77 provide a foundation for a more intensive and innovative analysis of energy flow magnitudes and patterns than was possible for the Gulf of Alaska/southeast Bering Sea data discussed above. A total of 978 transects provided information on seabird densities in 10′ X 10′ blocks, as depicted in Fig. 3.

Our initial analysis considers the energy dynamics of species populations as a function of linear distance from the nearest island (either St. Paul or St. George; distances were calculated from the center of the island to the center of a 10′ block, and the data then grouped by distance intervals). Tables 3-11 present the calculated energy demands (10^2 kcal km^{-2} day^{-1}) for the distance intervals according to census times; Tables 12-20 detail how the total energy flow for a given population at a specified time is allocated among the distance intervals, and Tables 21-28 present the relative contributions of species populations to the total "community" energy flow in each distance interval.

For most of the species there was moderate variability according to month and year, as well as in distance from nearest island. This, of course, is not surprising, given both the seasonal and annual fluctuations in actual densities that occur in seabird populations and the sampling error that is inevitable in ship-based censuses of wide-ranging and frequently discontinuously-distributed birds. For fulmars, for example, 74% of the total energy flow occurred within 40 km of the nearest island during July 1976, while only 31% of the July 1977 energy flow was in that distance zone. For shearwaters, on the other hand, the off-island distribution of energy flow was fairly stable at various times: 87% in "the 71-120-km zone in August 1975, 62% in the 91-100-km zone in July 1976, 63% in the 81-110-km zone in August 1977, but 45% in the 199-100-km zone in August 1977. Total energy flow through the total marine bird "community" also varied in both distribution and (especially) magnitude during the four census periods (Fig. 4). The average energy flow (weighted by total transect length censused per block) was lowest in August 1977 (15,300 kcal km^{-2} day^{-1}), intermediate in August 1975 and July 1977 (30,100 and 20,700 kcal km^{-2} day^{-1}, respectively), and substantially greater in July 1976 (80,000 kcal km^{-2} day-l). Associated with this was the extreme concentration of marine bird energy demands closer to islands during July 1976 than at other times. As is apparent from Fig. 4, murres accounted for most of the total "community" energy flow derived from these censuses (from 52% in August 1975 to 86% in July 1976). The distribution and magnitude of total marine bird energetic about the Pribilofs is thus driven largely by the requirements of murre populations.

Despite the monthly and annual differences in energy flow patterns, a consideration of average values for the combined censuses can provide a useful overview of the patterns typical of species populations. The overall weighted average energy flow peaked in the 11-40-km zone, trailing off with greater distances out to 200 km (Fig. 5). It is apparent that murres, the

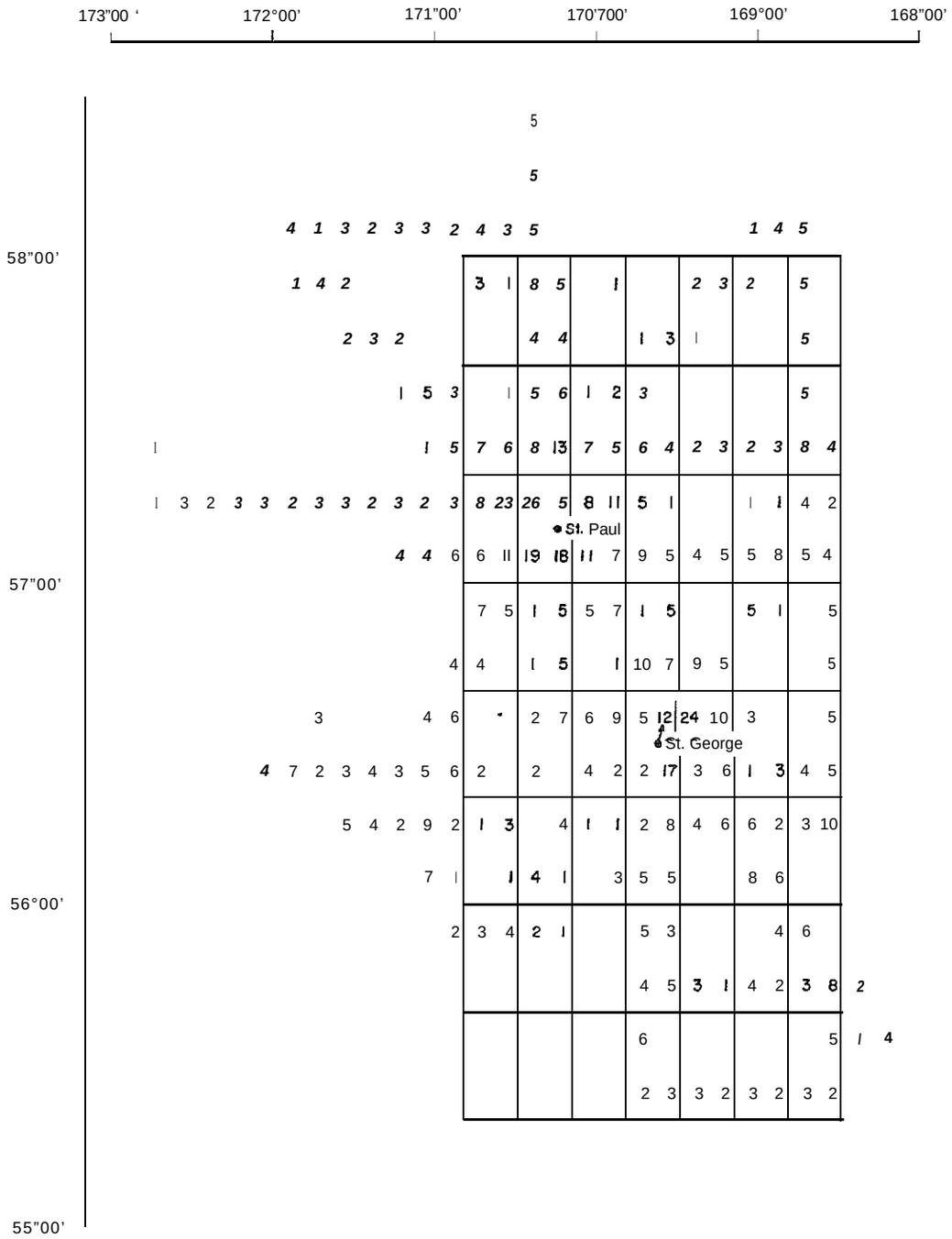

Fig. 3. Sampling intensity (number of transects censused) of marine bird surveys in the Pribilof Islands, 1975-77. Data are grouped by 10′ blocks; the grid represents the set of 20′ blocks used in the intensive analysis of spatial patterning of energy demands.

ENERGETIC DEMAND (KCAL A 100/DAY/KM2) FOR FUL

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	2	1	0	4	4	16	3	4	11	41	12	0	0	0	0	0	0	0	0	9
7/76	25	80	62	53	7	6	14	19	24	14	0	0	0	0	0	0	0	0	0	0	29
7/77	49	46	39	54	40	38	22	24	166	54	19	16	18	14	211	41	7	12	36	27	42
8/77	103	60	26	26	35	71	18	21	11	11	11	8	0	2	2	1	0	0	0	0	26
JULY	42	57	84	53	23	15	17	20	158	47	19	16	18	14	20	41	7	12	36	27	38
AUG	103	31	24	23	20	41	17	16	8	11	20	11	0	2	2	1	0	0	0	0	20
1977	62	52	61	39	37	61	18	22	72	31	14	15	19	11	17	37	7	12	36	27	35
ALL	53	46	56	40	21	28	17	17	52	25	20	14	18	11	17	37	7	12	36	27	29

Table 3. Estimated daily energy demand of fulmars in the Pribilof Islands area as a function of linear distance to nearest island. Values are averages for the 10′ census blocks occurring in a distance interval, weighted by the total transect length in that block.

ENERGETIC DEMAND (KCAL X 100/DAY/KM2) FOR SHW

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	ToT
3/75	0	15	13	18	21	31	17	273	27	89	61	274	0	0	0	0	0	0	0	0	101
7/76	3	0	0	1	0	1	0	0	0	8	0	0	0	0	0	0	0	0	0	0	1
7/77	to	20	1	8	11	1	1	8	1	3	2	3	1	1	6	2	1	4	7	69	5
8/77	5	2	1	2	2	1	2	4	8	7	34	6	0	1	3	0	0	0	0	0	4
JULY	8	14	1	4	5	1	1	5	1	4	2	3	1	1	6	2	1	4	2	69	4
AUG	5	8	3	5	11	14	5	105	15	39	42	211	0	1	3	0	0	0	0	0	3$
1977	9	13	1	5	5	1	1	5	5	5	23	4	1	1	6	2	1	4	2	69	5
ALL	7	12	2	5	9	8	3	76	11	25	32	78	1	1	6	2	1	4	2	69	21

Table 4. Estimated daily energy demand of Shearwaters in the Pribilof Islands area as a function of linear distance to nearest island. Values as in Table 3.

ENERGETIC DEMAND K AL (100/DAY/KM2) FOR FTP

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
3/75	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
7/76	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/77	1	1	2	1	1	1	1	0	2	0	1	1	9	1	1	16	0	0	2	19	2
8/77	1	3	0	1	11	8	2	3	1	18	1	0	0	2	0	1	0	0	0	0	5
JULY	0	0	2	1	1	0		0	2	0	1	1	9	1	1	16	0	0	2	19	2
AUG	1	2	0	1	5	4	1	2	1	17	7	0	0	0	0	1	0	0	0	0	4
1977	1		0	1	7	6	2	2		1	7	1	9	1	1	15	0	0	2	19	4
ALL	1	0	1	1	3	2	1	1	1	10	6	1	9	1	1	15	0	0	2	19	3

Table 5. Estimated daily energy demand of Fork-tailed Storm-Petrels in the Pribilof Islands area as a function of linear distance to nearest island. Values as in Table 3.

ENERGETIC DEMAND (KCAL 10°/DAY/KM2) FOR MUR

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	278	30	727	82	208	4[illegible]	13	37	1[illegible]	3	2	0	0	0	0	0	0	0	0	157
7/76	160	4132	02	1369	65	156	364	62	245	84	0	0	0	0	0	0	0	0	0	0	690
7/77	152	79	60	41	122	82	170	152	[illegible]	6	9	0	8	9	4	17	5	9	11	1	128
8/77	7	388	136	336	69	4[illegible]	27	46	54	39	23	12	0	4	1	4	0	0	0	0	104
JULY	54	117[illegible]	[illegible]7	894	93	136	257	50	73	45	9	10	8	9	4	17	5	9	11	1	299
AUG	[illegible]	333	229	415	75	118	3[illegible]	74	47	28	17	4	0	4	1	4	0	0	0	0	122
1977	16	186	341	383	90	58	61	76	57	38	19	10	8	8	4	15	5	9	11	0	117
AL	126	812	6	632	82	127	126	97	55	35	15	8	8	8	4	15	5	9	11		212

Table 7. Estimated daily energy demand of murres in the Pribilof Islands area as a function of linear distance to nearest island. Values as in Table 3.

ENERGETIC DEMAND (KCAL X 100/DAY/KM2) FOR KWS

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	13	29	16	17	17	15	20	13	33	22	24	0	0	0	0	0	0	0	0	20
7/76	6	11	43	64	11	14	48	14	28	8	0	0	0	0	0	0	0	0	0	0	32
7/77	28	34	121	46	14	23	26	7	14	4	11	7	4	7	14	1	4	2	4	0	22
8/77	17	16	21	25	9	4	10	6	6	8	14	6	0	2	7	1	0	0	0	0	11
JULY	22	28	30	55	13	16	39	10	15	5	11	7	4	7	14	1	4	2	4	0	25
AUG	17	16	22	23	13	9	12	11	8	18	17	20	0	2	7	1	0	0	0	0	14
1977	25	29	69	35	11	10	14	6	9	6	13	7	4	6	13	1	4	2	4	0	17
ALL	21	23	60	41	13	13	22	11	10	13	15	11	4	6	13	1	4	2	4	0	20

Table 6. Estimated daily energy demand of kittiwakes in the Pribilof Islands area as a function of linear distance to nearest island. Values as in Table 3.

ENERGETIC DEMAND (KCAL X 100/DAY/KM2) FOR AUK

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
3/75	0	1	1	4	1	3	4	1	1	0	2	0	0	0	0	0	0	0	0	0	1
7/76	10	13	57	71	22	19	57	5	6	1	0	0	0	0	0	0	0	0	0	0	37
7/77	1	0	0	3	2	0	2	2	1	1	3	0	0	0	0	0	0	3	0	0	1
9/77	0	0	1	4	1	0	1	1	0	0	0	1	0	1	2	0	0	0	0	0	1
JULY	4	4	23	36	12	14	35	3	1	1	3	0	0	0	0	0	0	3	0	0	12
AUG	0	1	1	4	1	1	1	1	0	0	1	1	0	1	2	0	0	0	0	0	1
1977	1	0	1	3	1	0	1	2	1	0	1	0	0	0	0	0	0	3	0	0	1
ALL	3	2	13	22	6	7	14	2	1	0	1	0	0	0	0	0	0	3	0	0	7

Table 8. Estimated daily energy demand of auklets in the Pribilof Islands area as a function of linear distance to nearest island. Values as in Table 3.

ENERGETIC DEMAND (KCAL 100/DAY/KM2) FOR PUF

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	1	3	2	3	2	3	4	1	0	0	0	0	0	0	0	0	0	0	0	2
7/76	6	9	10	8		6		4	0	1	0	0	0	0	0	0	0	0	0	0	7
7/77	3	4	3	4	2	1	2	1	1	1	1	0	1	0	0	0	1	1	1	0	1
8/77	1	3	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1
JULY	4	5	6	5	5	5	6	2	1	1	1	0	1	0	0	0	1	1	1	0	3
AUG	1	2	2	2	2	1	1		1	0	0	0	0	0	0	0	0	0	0	0	1
1977	2		4	2	2	1	1	1	1	1	1	0	1	0	0	0	1	1	1	0	1
ALL	3	4		4	3	3	3	2	1	1	1	0	1	0	0	0	1	1	1	0	2

Table 9. Estimated daily energy demand of puffins in the Pribilof Islands area as a function of linear distance to nearest island. Values as in Table 3.

ENERGETIC DEMAND (KCAL X 100/DAY/KM2) FOR MIS

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
3/75	0	7	1	8	1	5	1	1	2	73	1	2	0	0	0	0	0	0	0	0	10
7/76	3	2	2	2	8	4	13	2	0	5	0	0	0	0	0	0	0	0	0	0	4
7/77	1	1	2	30	11	1	1	1	2	1	0	7	2	2	2	2	3	3	1	9	6
9/77	0	0	1	1	0	1	1	1	1	2	2	3	0	1	1	2	0	0	0	0	1
JULY	2	1	2	10	10	3	8	2	2	2	0	7	2	2	2	2	3	3	1	9	5
AUG	0	3	1	3	1	3	1	1	1	32	1	2	0	1	1	2	0	0	0	0	4
1977	1	0	1	14	5	1	1	1	1	1	1	7	2	2	2	2	3	3	1	9	4
ALL	1	2	1	10	4	3	4	1	1	20	1	6	2	2	2	2	3	3	1	9	5

Table 10. Estimated daily energy demand of miscellaneous species in the Pribilof Islands area as a function of linear distance to nearest island. Values as in Table 3.

ENERGETIC DEMAND (KCAL x 100/DAY/KM2) FOR TOT

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	31[illegible]	692	[illegible]	123	270	46	42[illegible]	85	237	130	314	0	0	0	0	0	0	0	0	301
7/76	213	4247	[illegible]	1569	120	206	505	202	303	121	0	0	0	0	0	0	0	0	0	0	800
7/77	245	187	83	[illegible]	203	147	225	135	250	100	46	44	43	34	47	79	21	34	57	125	207
8/77	134	474	19[illegible]	336	123	132	62	85	82	86	95	36	0	11	16	9	0	0	0	0	153
JULY	236	128[illegible]	[illegible]	1064	162	190	393	198	253	105	46	44	43	34	47	79	21	34	57	125	388
AUG	134	396	88	476	123	191	63	212	81	145	105	248	0	11	16	9	0	0	0	0	204
1977	217	265	41	432	158	138	103	115	147	32	79	44	43	29	43	72	21	34	57	125	184
ALL	215	102	610	805	141	191	190	207	132	129	91	118	43	29	*3	72	21	34	57	125	299

Table 11. Estimated daily energy demand of the total marine bird "community" in the Pribilof Islands area as a function of linear distance to nearest island. Values as in Table 3.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR FUL

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	[illegible]	140	150	160	170	180	190	200	TOT
8/75	0	2	2	0		3	1	6		9	33	10	0	0	0	0	0	0	0	0	
7/76	8	27	2	8	2	2	6	5	3	5	0	0	0	0	0	0		0	0	0	
7/77	5	6	12	[illegible]	5	5	3		2	7	2	2	2	2	2	5		0	4	3	
8/77	25	5	[illegible]	0	9	17	4	5	3		3	2	0	0	0	0		0	0	0	
JULY	6	8	12	7	3	2	2	3	22	6	3	[illegible]	2	2		6		[illegible]	5	4	
AUG	1	[illegible]	[illegible]	7	6	12	5	5	2	3	6	3	0	1	1	0		0	0	0	
1977	10	6	9	6	6	9	3	3	1	5	2	2	3	[illegible]		6		[illegible]	5	4	
ALL	0	6	10	7	4	5	[illegible]	3		4	4	3	3	2		7		2	6	5	

Table 12. Percentages of population energy demand of fulmars occurring in intervals of distance from nearest island.

RELATIVE ENERGY DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR SHW

ISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	2	0	2	3	4	2	33		11	7	3	0	0	0	0	0	0	0	0	
7/76	23	0	0	8	0	6	0	0	0	62	0		0	0	0	0	0	0	0	0	
7/77	6	13	1	5	7	1	1	0		2	1	2	1		4	1	1	3	1	45	
8/77	6	3		3	3	2	3	5	10	9	44	8	0	1	4	0	0	0	0	0	
JULY	6	10		3	4	1	1	4		3	1	2	1	1	4	1	1	3	1	51	
AUG	1	2			2	3	1	22	3	8	9	45	0	0	1	0	0	0	0	0	
1 77	6	0	1	3	3	1	1	3		3	14	2		1	4	1	1	2		42	
ALL	2	3	1			2	1	21	3	7	9	22	0	0	2	1	0		1	19	

Table 13. Percentages of population energy demand of shearwaters occurring in intervals of distance from nearest island.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR FTP

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	0			0	0		0	0	00	0	0	0	0	0	0	0	0	0	0	
7/76	0	0	67	3		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
7/77	2	2	3	2	2	2	2	0	3	0	2	2	5	2	2	27	0	0		32	
8/77		4	2	1	6	2		1	1	27	15	0	0	0	0	1	0	0	0	0	
JULY			4	2	2	0	0	0	4	0	2	2	16	2	2	29	0	0	4	34	
A	2	4		2		8	2	4	2	5	15	0	0	0	0	2	0	0	0	0	
7	1		6		5	7	2	2	1	11	8	1	0	1		16	0	0	2	21	
ALL			5		2	3					8				1	19	0	0		24	

Table 14. Percentages of population energy demand of Fork-tailed Storm-Petrels occurring in intervals of distance from nearest island.

RELATIVE [illegible] TOTAL [illegible] ALL INTERVAL [illegible] KWS

DISTANCE TO NEAREST ISLAND (KM)

	10	20	[illegible]	40	[illegible]	60	[illegible]	[illegible]	90	100	110	120	130	140	150	160	170	180	190	200	TOT
/75	[illegible]	6	1	[illegible]	3	8	7	9	6	15	0	1	0	0	0	0	0	0	0	0	
76	2	4		26	[illegible]	6	1	5	11	3	0	0	0	0	0	0	0	0	0	0	
/77	8	[illegible]	3	12	4	6	7	2	4	1	3	2	1	2	4	0	1	1	[illegible]	0	
/7	1	[illegible]		16	6	3	6		4	5	9	4	0	1	5	1	0	0		0	
JL	[illegible]	8	2	6		5	11	3	4		3	2	1	2	4	0	1	[illegible]	1	0	
A G	9	5	1	2	7	5	6	6	4	9	9	10	0	1	4	1	0	0	0	0	
1 7	[illegible]	1	2	3	4	4	5	2	3	2	5	3	1	2	5	0	1	1	1	0	
ALL	7	5	21	1	5	[illegible]	3	[illegible]	3	5	5	4	1	2	5	0	1	1	1	0	

Table 15. Percentages of population energy demand of kittiwakes occurring in intervals of distance from nearest island.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR MUR

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	13	29	34	4		2	5	2	1	0	0	0	0	0	0	0	0	0	0	
7/76	2	5	1		1	2	5	2			0	0	0	0	0	0		0	0	0	
7/77	8	4	24	23	5	4				2	0	1	0	0	0	1	0	0		0	
8/77		32	1	28	5	4	2	4	5		2	1	0	0	0	0	0	0	0	0	
JULY	4	3		2	2	4	8	4	2	1	0	0	0	0	0	0	0	0	0	0	
AUG		24	1	0	5	9	2	5	3	2	1	0	0	0	0	0	0	0	0	0	
1 77	8	2	23	26	5	4	4	5	4	3		0	1		0	1				0	
ALL	5	30	1	25	3	5	5	4	2	1		0	0	0	0	1	0	0	0	0	

Table 16. Percentages of population energy demand of murres occurring in intervals of distance from nearest island.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR AUK

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
7/5	0	0	0	22		7	22	0	0	0	11	0	0	0	0	0	0	0	0	0	
7/6	4	5	32	27	8	7	22	2	2	0	0	0	0	0	0	0	0	0	0	0	
7/7	6	0		17	11	0	1	11	0	6	17	0		0	0	0	0	17	0	0	
8/7	0	0	0	33	8	0	8	8	0	0	0	8		8	17	0	0	0	0	0	
JULY	3	3	1	26	9	10	25	2	1	1	2	0	0	0	0	0	0	2	0	0	*
AUG	0		4	29	1	7	7	7		0	7	0	0	7	14	0	0	0	0	0	
13/7	7			21	7	0	7	14		0	7	0	0	0	0	0	0	24	0	0	0
ALL	4		16	0	0	9	19		1	0	1	0	0	0	0	0	0	4	0	0	

Table 17. Percentages of population energy demand of auklets occurring in intervals of distance from nearest island.

RELATIVE PROBABILITY (% OF TOTAL FOR ALL INTERVALS) FOR PUF

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
3/75	0				6	1	5	21	5	0	0	0	0	0	0	0	0	0	0	0	
7/76		3	7		2	10	5	7		2	0	0	0	0	0	0	0	0	0	0	
7/77		6		15	7	4		4	4	4	4	0	4	0	0	0	4	4	4	0	
3/77		25			3	0		3	3	8	8	0	0	0	0	0	0	0	0	0	
JULY	4		3		11	1	13	4	2	2	2	0	2	0	0	0	2	2	0	0	
AUG		4			14	7	7	4			0	0	0	0	0	0	0	0	0	0	
1977	9	1	9		9	5	3	5	5	5	5	0	5	0	0	0	5	5	5	0	
ALL		7	2	12	9			6		3	3	0		0	0	0	3		3	0	

Table 18. Percentages of population energy demand of puffins occurring in intervals of distance from nearest island.

RELATIVE ENERGETIC [illegible] TAL FOR ALL [illegible] FOR MIS

DISTANCE TO NEAREST ISLAND (KM)

	10	20	[illegible]	[illegible]	[illegible]	60	70	[illegible]	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75					1				2		1	2		0	0	0	0	0	0	0	
7/76	[illegible]				20		32	[illegible]		2	0	0	0	0	0	0	[illegible]	0	0	0	
7/77			[illegible]	[illegible]	1			1	2	1	0	9	2	[illegible]	2	[illegible]	4	4	1	11	0
[illegible]		0	[illegible]	[illegible]			0	[illegible]	[illegible]	12	12	8	0	6	6	1[illegible]	0	0	0	0	
[illegible]	3		[illegible]	2	13	4			3	3	0	9	3	3	3	3	4	4	1	11	
A G	[illegible]	[illegible]	[illegible]	[illegible]	2	6	2	2	[illegible]	6	2	4	0	[illegible]	2	4	0	0	0	0	
1	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	2	2	2	2	3	3	3	3	5	5	2	16	
ALL	[illegible]	3	[illegible]	[illegible]	[illegible]	4	[illegible]	1[illegible]		26	1	8	3	3	3	3	4	4	1	12	

Table 19. Percentages of population energy demand of miscellaneous species occurring in intervals of distance from nearest island.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR TOT

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
9/75	0	9	20	23	4	8	5	12	2	7	4	9	0	0	0	0	0	0	0	0	
7/76	3	50	12	19	1	2	6	2	0	1	0	0	0	0	0	0	0	0	0	0	
7/77	7	6	23	17	6	4	7	6	0	3	1	1	1	1	1	2	1	1	2	4	
9/77	7	24	10	20	7	7	3	4	4	4	5	2	0	1	1	0	0	0	0	0	
JULY	4	24	16	20	3	4	7	4	5	2	1	1	1	1	1	1	0	1	1	2	
AUG	5	16	11	14	5	6	3	9	3	6	4	10	0	0	1	0	0	0	0	0	
1977	8	10	17	17	6	5	4	4	5	3	3	2	2	1	2	3	1	1	2	5	
ALL	5	22	15	19	3	5	5	5	3	3	2	3	1	1	1	2	1	1	1	3	

Table 20. Percentages of total marine bird "community" energy demand occurring in intervals of distance from nearest island.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL SPECIES) FOR FUL

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	1	2		3	1	17	2	5	5	32	4	0	0	0	0	0	0	0	0	3
7/76	12	2		3	6	3	3	[illegible]	3	12	0	0	0	0	0	0	0	0	0	0	4
7/77	20	26	13	9	20	26	10	12	66	54	41	36	42	41	43	52	33	35	63	22	20
8/77	77	13	13	7	27	[illegible]	2	25	13	13	12	22	0	18	13	11	0	0	0	0	17
JULY	18	4	0	5	14	8	4	1	62	45	41	36	42	41	43	52	33	35	63	22	10
AUG	77	8	[illegible]	[illegible]	16	21	25	3	10	8	19	4	0	18	13	11	0	0	0	0	10
1977	2	15	13	6	23	4	19	19	49	34	18	34	42	38	40	51	33	35	63	22	19
ALL	25	[illegible]	16	5	15	15		8	39	19	22	12	42	38	40	51	33	35	63	22	10

Table 21. Percentages of total "community" energy flow contributed by fulmars in intervals of distance from nearest island.

RELATIVE ENERGETIC FLOW (% OF TOTAL FOR ALL SPECIES) FOR SHW

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
7/75	0	0	0	2	13	1	18	6	32	8	47	87	0	0	0	0	0	0	0	0	34
7/76		0	0	0	0	0		0		7	0	0	0	0	0	0	0	0	0	0	0
7/77	4	1	0		5		0	4	0		4	7	2	3	13	3	5	12	4	55	2
8/77	4	0			2			5	10	8	36	17	0	9	9	0	0	0	0	0	3
JULY	3		0	0			0		0		4	7	2	3	13	3	5	12	4	55	1
AUG	4	2				7	7	50	1	2	4	85	0	9	19	0	0	0	0	0	19
1-7	4	5	0	1	3		1	4		2	29	9	2	3	14	3	5	12	4	55	3
ALL	3		0	1	5	4	2	37	8	1	35	66	2	3	14	3	5	12	4	55	7

Table 22. Percentages of total "community" energy flow contributed by shearwaters in intervals of distance from nearest island.

RELATIVE ENERGY DEMAND (% OF TOTAL FOR ALL SPECIES) FOR TP

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75			-	0	0	0		0	0	6	0	0	0	0		0	0	0	0	0	0
7/76	0	0	[illegible]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/[illegible]	0		0		0	1	0		1	0	2	2	21	3	2	20	0	0	4	5	1
8/77	1	1		0	9	6	3			21	11	0	0	0	0	11	0	0	0	0	3
LY	0		-	0	1	0	0	0	1	0	2	2	21	3	2	20	0	0	4	15	1
AUG			2	0		2	1	1	1	12	7	0	0	0	0	11	0	0	0	0	2
77	0	0		0		4	[illegible]	2	1	11	9	2	21	3	2	21	0	0	4	15	2
ALL			1	0		1	1	0		8	7	1	21	3	2	21	0	0	4	15	1

Table 23. Percentages of total "community" energy flow contributed by Fork-tailed Storm-Petrels in intervals of distance from nearest island.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL SPECIES) FOR KWS

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	4	4	2	13	6	16	5	15	14	17	8	0	0	0	0	0	0	0	0	7
7/76	3	0			9	7	10	7	9	7	0	0	0	0	0	0	0	0	0	0	4
7/77	11	18	15	2	7	16	12	4	6	4	24	16	9	21	30	1	19	6	7	0	11
8/77	13	14	11	6	7	3	16	7	7	9	15	17	0	18	44	11	0	0	0	0	7
JULY	9	2	10	5	9	8	10	5	6	5	24	16	9	21	30	1	19	6	7	0	6
AUG	13	[illegible]	[illegible]	5	10	5	18	5	10	12	16	8	0	18	44	11	0	0	0	0	7
1977	12	10	14	7	7	7	14	5	6	7	16	16	9	21	30	1	19	6	7	0	9
ALL	10	3	10	5	9	7	12	5	8	10	16	9	9	21	50	1	19	6	7	0	7

Table 24. Percentages of total "community" energy flow contributed by kittiwakes in intervals of distance from nearest island.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL SPECIES) FOR MUR

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
6/75	0	85	91	93	64	77	42	23	44	5	2	1	0	0	0	0	0	0	0	0	5.2
7/76	75	97	82	87	54	76	72	80	81	69	0	0	0	0	0	0	0	0	0	0	86
7/77	62	42	71	79	60	56	76	78	23	36	20	23	13	26	9	22	24	26	19	1	62
8/77	5	82	70	85	54	36	44	56	66	45	24	33	0	36	6	44	0	0	0	0	68
JULY	65	92	76	84	57	72	73	79	29	43	20	23	19	26	9	22	24	26	19	1	77
AUG	5	84	80	87	53	62	44	35	53	19	16	2	0	36	6	44	0	0	0	0	60
1977	53	65	71	79	57	42	61	66	39	41	24	23	19	28	9	21	24	26	19	1	64
ALL:	59	90	77	85	58	66	66	47	42	27	16	7	19	28	9	21	24	26	19	1	71

Table 25. Percentages of total "community" energy flow contributed by murres in intervals of distance from nearest island.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL SPECIES) FOR AUK

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	0	0	1	1	1	4	0	1	0	2	0	0	0	0	ox	0	0	0	0	0
7/76	5	0		5	18	9	11	2	7	1	0	0	0	0	0	0	0	0	0	0	5
7/77	0	0	0	1	1	0	1	1	0	1	7	0	0	0	0	0	0	9	0	0	0
8/77	0	0	1	1	1	0	2	1	0	0	0	3	0	9	13	0	0	0	0	0	1
JULY	2	0	3	3		7	9	2	0	1	7	0	0	0	0	0	0	9	0	0	3
AUG	0	0		1	1	1	1	0	0	0	1	0	0	9	13	0	0	0	0	0	0
1977	0	0	0	1	1	0	1	2	1	0	1	0	0	0	0	0	0	9	0	0	1
ALL	1	0	2	5	4	4	7	1	1	0	1	0	0	0	0	0	0	9	0	0	2

Table 26. Percentages of total "community" energy flow contributed by auklets in intervals of distance from nearest island.

RELATIVE ENERGETIC DEMAND % OF TOTAL FOR ALL SPECIES FOR PUF

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0									0	0	0	0	0	0	0	0	0		0	1
7/76		0		1	0	3	0	2	0	1	0	0	0	0	0	0	0	0	0	0	
7/77		2		1	1			1	0	1	2	0	2	0	0	0	5	3	2	0	0
8/77	1		1	0	1	0	2	1		1	1	0	0	0	0	0	0	0	0	0	1
JULY	2			0	3	3	2	1	0	1	2	0	2	0	0	0	5	3	2	0	1
AUG			1	0	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1/77			0	0	1	1	1	1		1	1	0	2	0	0	0	5	3	2	0	1
[illegible]	1	0		0	2	2	2	1	1	1	1	0	2	0	0	0	5	3	2	0	1

Table 27. Percentages of total "community" energy flow contributed by puffins in intervals of distance from nearest island.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL SPECIES) FOR MIS

DISTANCE TO NEAREST ISLAND (KM)

	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	TOT
8/75	0	2	0	1	1	2	1	0	2	33	1	1	0	0	0	0	0	0	0	0	3
7/76	1	0	0	0	7	2	3	1	0	4	0	0	0	0	0	0	0	0	0	0	0
7/77	0	1	0	5	5	1	0	1	1	1	0	16	5	6	4	3	14	9	2	7	3
8/77	0	0	1	0	0	1	2	1	1	2	2	8	0	9	5	22	0	0	0	0	1
JULY	1	0	0	2	6	2	2	1	1	2	0	16	5	6	4	3	14	9	2	7	1
AUG	0	1	0	1	1	2	1	0	1	22	1	1	0	9	6	22	0	0	0	0	2
1977	0	0	0	3	3	1	1	1	1	1	1	16	5	7	5	3	14	9	2	7	2
ALL	0	0	0	1	3	2	2	0	1	16	1	5	5	7	5	3	14	9	2	7	2

Table 28. Percentages of total "community" energy flow contributed by miscellaneous species in intervals of distance from nearest island.

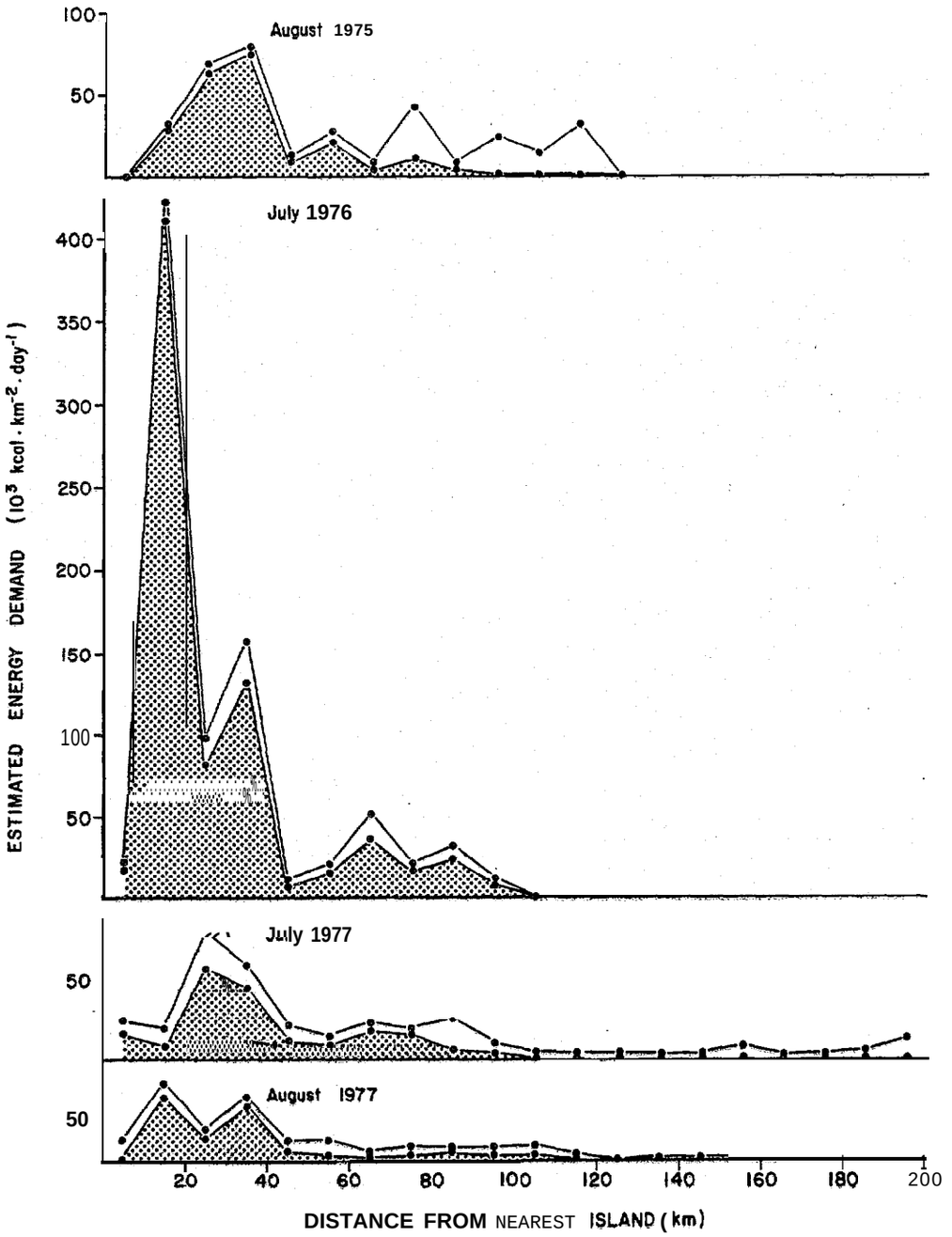

Fig. 4. Distribution of total "community" energy demand as a function of distance from nearest island in the Pribilof Islands marine bird system. The shaded area represents the energy demand of murre populations.

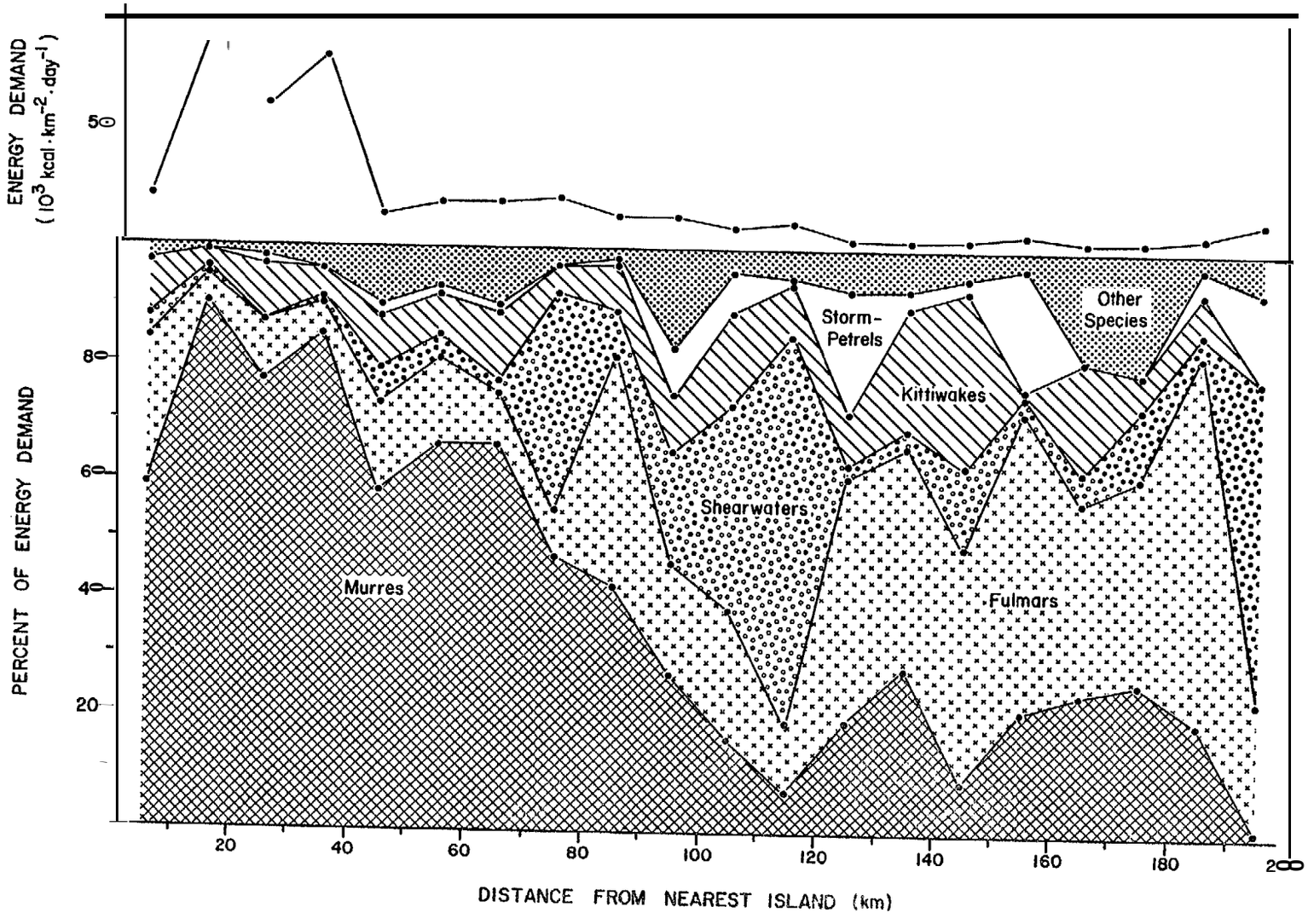

Fig. 5. Distribution of total "community" energy demand (above) and of the percentage contribution of each species or species group to that total energy flow, as a function of distance from the nearest island. This analysis represents weighted averages for all censuses in the Pribilof Islands combined.

energetically dominant species in this system, were concentrated in these relatively near intervals; 77% of the total energy flow through murre populations occurred within 40 km of the nearest island (Table 29), although energy flow was' relatively low close to islands. The proportionate contribution of murres to the total community energy demand fell off beyond 60 km. Fulmars accounted for a moderate portion of the total community energetic, but assumed greatest importance at greater distances, beyond 120 km (Fig. 5); half of the total energy flow through fulmars occurred beyond 80 km (Table 29). Fork-tailed Storm-Petrels, while never an important component of community energetic, exhibited an off-island distributional pattern similar to that of fulmars, with 59% of their energy demand occurring beyond 120 km. Shearwaters contributed a major portion of the community energetic in intermediate distance intervals; 41% of their energy demand was concentrated between 80 and 120 km. The energy demand of kittiwakes occurred primarily close to islands (Table 29), although the proportional contribution of the species to the community total was rather uniform over the entire area considered (Fig. 5). Auklets and puffins also exhibited greatest energy demands relatively near to islands, although that of puffins was more widely distributed than that of auklets (Table 29); neither group contributed significantly to total community energetic.

The uneven distance patterns revealed above may be associated with fundamental variations in oceanographic conditions. To explore this possibility in a preliminary fashion, we determined the water depth for each of the 10' X 10' blocks used in the initial analysis (Fig. 3) from National Ocean Survey hydrographic charts, and then grouped the weighted average energy flow values for blocks by water depth categories. The resulting data are presented in Tables 30-55; the weighted averages for all censuses are summarized in Fig. 6. Community energy demand was greatest in relatively shallow waters, a consequence of the concentration of murre densities in such regions. Auklets as a group also demonstrated a distinct association with shallow areas. Fulmar and shearwater energy demands were greatest in 120-140-km waters and in deeper areas, and storm-petrels were distributed over areas with water depths exceeding 100 m, with their energy demands peaking in deep-water zones. The energy demands of kittiwakes were broadly distributed over depth categories, but peaked in the 200-600-m interval.

The foregoing analysis of the distribution of energy demands considered distance from the nearest island or water depth without regard to the identity of the island or the specific latitude-longitude locations or depths of zones of substantial energy flow. However, in the Pribilof group St. George supports the major portion of the islands' breeding seabirds. Hickey (1977) reported that on the order of 2.5 million seabirds bred on St. George during 1976, compared with 0.25 million on St. Paul; his group estimated a breeding population of 1.5 million Thick-billed Murres on St. George. compared with 110,000 on St. Paul. Further, the continental shelf break is not far to the south of the islands, while immediately to the north the waters are relatively shallow. We have therefore analyzed the census data from the most completely-censused areas about St. George and St. Paul more intensively. Censuses conducted within the area 55°20' to 58°00' N latitude and 168°30' to 170°50' longitude were combined to calculate overall bird densities by species within 20' X 20' blocks (Fig. 3); the intensity of transect censusing in these blocks over the

Table 29. Percentages of energy demand for species populations as a function of distance from the nearest island, calculated from weighted average values from all censuses combined.

Species	Distance from nearest island (km)				
	0-40	41-80	81-120	121-160	161-200
Fulmar	35	15	20	15	14
Shearwaters	7	27	41	3	21
Fork-tailed Storm-Petrel	8	9	23	32	27
Kittiwakes	50	22	17	8	3
Murres	77	17	4	1	0
Anklets	55	39	2	0	4
Puff ins	45	33	9	3	9
TOTAL	61	18	11	5	6

ENERGETIC DEMAND KCAL X 100/DAY/KM2) FOR FUL

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	2	2	5	16	22	13	25	28	13	9
7/76	13	21	52	67	0	151	114	0	0	29
7/77	23	8	17	52	329	58	94	60	59	42
8/77	11	5	8	52	25	85	46	46	28	26
JULY	16	11	24	56	329	72	97	60	59	38
AUG	4	4	7	43	23	48	41	41	27	20
1977	19	7	14	52	195	70	74	53	37	35
ALL	12	8	17	49	132	58	72	49	35	29

Table 30. Distribution of fulmar energy demand by intervals of water depth.

ENERGETIC DEMAND (KCAL x 100/DAY/KM2) FOR SHW

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	21	160	43	20	177	47	62	270	229	101
7/76	0	2	1	1	0	0	0	0	0	1
7/77	0	2	4	8	0	3	13	8	23	5
8/77	1	8	1	1	4	3	3	3	5	4
JULY	0	2	3	5	0	3	13	8	23	4
AUG	16	61	14	6	103	26	17	75	27	38
1977	0	5	3	4	2	3	10	5	10	5
ALL	5	31	8	6	66	17	15	47	26	21

Table 31. Distribution of shearwater energy demand by intervals of water depth.

ENERGETIC DEMAND (K CAL X 100/DAY/KM2) FOR FTP

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	0	0	0	0	5	0	0	18	0	1
7/76	0	0	1	0	0	5	7	0	0	0
7/77	0	0	0	13	3	4	2	2	2	3
8/77	0	0	0	5	8	30	12	22	4	5
JULY	0	0	0	9	3	4	3	2	2	2
AUG	0	0	0	4	6	14	9	21	4	4
1977	0	0	0	9	5	15	6	12	4	4
ALL	0	0	0	6	5	10	6	13	3	3

Table 32, Distribution of Fork-tailed Storm-Petrel energy demand by intervals of water depth.

ENERGETIC DEMAND (KCAL X 100/DAY/KM2) FOR KWS

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	14	13	7	30	29	14	36	53	39	20
7/76	35	13	26	56	0	22	80	0	0	32
7/77	10	7	4	26	28	30	134	24	24	22
8/77	1	3	9	13	33	12	27	19	11	11
JULY	28	9	8	34	28	29	126	24	24	25
AUG	11	7	8	21	31	13	29	28	14	14
1977	7	5	6	22	30	23	88	21	15	17
ALL	22	8	8	27	30	20	82	26	17	20

Table 33. Distribution of kittiwake energy demand by intervals of water depth.

ENERGETIC DEMAND (KCAL X 100/DAY/KM2) FOR MUR

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
3/75	372	130	33	40	90	32	449	5	0	157
7/76	955	136	1690	100	0	10	80	0	0	690
7/77	1103	80	25	15	2	2	24	8	12	128
8/77	646	118	125	102	25	20	49	11	6	104
JULY	996	94	382	37	2	3	33	8	12	299
AUG	444	122	95	86	62	26	145	10	5	122
1977	955	97	62	62	12	9	35	10	7	117
ALL	810	108	262	64	41	16	84	9	7	212

Table 3C. Distribution of murre energy demand by intervals of water depth.

ENERGETIC DEMAND (KCAL X 100/DAY/KM2) FOR AUK

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	2	2	2	0	0	0	0	1	0	1
7/76	70	7	0	9	0	0	0	0	0	37
7/77	5	1	1	1	0	0	0	0	0	1
8/77	11	1	1	1	0	0	0	0	0	1
JULY	52	3	1	3	0	0	0	0	0	12
AUG	4	2	2	0	0	0	0	0	0	1
1977	7	1	1	1	0	0	0	0	0	1
ALL	36	2	1	2	0	0	0	0	0	7

Table 35. Distribution of auklet energy demand by intervals of water depth.

ENERGETIC DEMAND (KCAL × 100/DAY/KM2 FOR PUF

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	3	3	2	1	1	2	0	0	1	2
7/76	8	6	3	3	0	12	5	0	0	7
7/77	3	2	1	2	0	1	2	1	2	1
8/77	3	1	1	1	0	0	1	1	1	1
JULY	6	3	1	3	0	3	2	1	2	3
AUG	3	2	1	1	1	1	1	0	1	1
1977	3	1	1	1	0	1	2	1	1	1
ALL	5	2	1	2	1	2	2	0	1	2

Table 36. Distribution of puffin energy demand by intervals of water depth.

ENERGETIC DEMAND (KCAL x 100/DAY/KM2) FOR MIS

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	5	3	2	1	1	4	1	140	1	10
7/76	8	2	0	0	0	0	3	0	0	4
7/77	40	1	2	12	0	1	2	2	2	6
8/77	1	1	1	1	1	1	0	0	1	1
JULY	17	1	1	9	0	1	2	2	2	5
AUG	4	2	1	1	1	2	0	38	1	4
1977	27	1	1	6	0	1	1	1	2	4
ALL	12	2	1	4	1	2	1	23	2	5

Table 37. Distribution of energy demands of miscellaneous species by intervals of water depth.

ENERGETIC DEMAND (KCAL X 100/DAY/KM2) FOR TOT

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	419	313	94	108	325	112	573	515	283	301
7/76	1089	187	1973	241	0	200	289	0	0	800
7/77	1184	101	54	129	362	99	273	105	124	207
8/77	674	137	146	181	96	151	138	102	56	153
JULY	1115	123	420	157	362	115	276	105	124	388
AUG	486	200	128	162	227	130	242	213	79	204
1977	1018	117	88	157	244	122	216	103	76	184
ALL	902	161	298	160	276	125	262	167	91	299

Table 38. Distribution of total community energy demand by intervals of water depth.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR FUL

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	1	1	6	12	16	10	19	21	10	
7/76	3	5	12	13	0	34	26	0	0	
7/77	3	1	2	7	44	8	13	8	8	
8/77	3	2	2	16	8	26	14	14	8	
JULY	2	1	3	7	43	9	13	8	8	
AUG	2	2	3	17	9	19	16	16	10	
1977	3	1	3	9	35	13	13	10	7	
ALL	3	2	4	11	29	13	16	11	8	

Table 39. Percentages of energy demand of fulmars occurring in water depth intervals.

RELATIVE EN ERGET IC DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR SHW

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	2	14	4	2	16	4	5	24	20	
7/76	0	40	20	20	0	0	0	0	0	
7/77	0	3	6	12	0	4	22	12	34	
8/77	3	24	3	3	12	9	9	9	15	
JULY?	0	3	5	10	0	5	21	13	37	
AUG	4	IQ	4	2	27	7	4	20	7	
1977	0	11	6	9	4	6	21	11	21	
ALL	2	13	3	2	27	7	6	19	11	

Table 40. Percentages of energy demand of shearwaters occurring in water depth intervals.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR FTP

DEPTH M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	0	0	0	0	21	0	0	75	0	
7/76	0	0	8	0	0	38	54	0	0	
7/77	0	0	0	46	11	14	7	7	7	
8/77	0	0	0	6	9	35	14	26	5	
JULY	0	0	0	36	12	16	12	8	8	
AUG	0	0	0	6	10	23	15	34	6	
1977	0	0	3	16	9	27	11	22	7	
ALL	0	0	0	13	11	22	13	28	7	

Table 41. Percentages of energy demand of Fork-tailed Storm-Petrels occurring in water depth intervals.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR KWS

	DEPTH (M)									
	60	80	100	120	140	200	600	1400	3000	ALL
8/75	5	5	3	12	11	5	14	21	15	
7/76	13	5	10	21	0	8	30	0	0	
7/77	3	2	1	8	9	10	43	8	8	
8/77	1	2	6	13	23	8	19	13	8	
JULY	8	3	2	10	8	9	38	7	7	
AUG	6	4	5	12	18	7	16	16	8	
1977	3	2	3	9	13	10	38	9	6	
ALL	8	3	3	10	12	8	32	10	7	

Table 42. Percentages of energy demand of kittiwakes occurring in water depth intervals.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR MUR

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
6/75	28	10	3	3	7	2	34	0	0	
7/76	25	4	49	3	0	0	2	0	0	
7/77	79	6	2	1	0	0	2	1	1	
8/77	54	10	10	8	2	2	4	1	0	
JULY	53	5	20	2	0	0	2	0	1	
AUG	40	11	9	8	6	2	13	1	0	
1977	70	7	5	5	1	1	3	1	1	
ALL	50	7	15	4	3	1	5	1	0	

Table 43. Percentages of energy demand of murres occurring in water depth intervals.

RELATIVE ENERGETIC DEMAND % OF TOTAL FOR ALL INTERVALS FOR AUK

DEPTH M)

	60	8≤	1≤0	12°	140	200	600	1400	3000	ALL
8/75	25	25	25	0	0	0	0	13	0	
7/76	57	6	0	7	0	0	0	0	0	
7/77	56	11	11	11	0	0	0	0	0	
8/77	73	7	7	7	0	0	0	0	0	
JULY	73	4	1	4	0	0	0	0	0	
AUG	44	22	22	0	0	0	0	0	0	
1977	64	9	9	9	0	0	0	0	0	
ALL	75	4	2	4	0	0	0	0	0	

Table 44. Percentages of energy demand of auklets occurring in water depth intervals.

RELATIVE ENERGETIC DEMAND % OF TOTAL FOR ALL INTERVALS FOR PUF

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	20	20	13	7	7	13	0	0	7	
7/76	16	12	6	16	0	24	10	0	0	
7/77	20	13	7	13	0	[illegible]	13	7	13	
8/77	30	10	10	10	0	0	10	10	10	
JULY	25	13	4	13	0	13	8	4	8	
AUG	25	17	8	8	8	8	8	0	8	
1977	25	8	8	8	0	8	17	8	8	
ALL	28	11	6	11	6	11	11	0	6	

Table 45. Percentages of energy demand of puffins occurring in water depth intervals.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL INTERVALS) FOR MIS

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	3	2	1	1	1	2	1	83	1	
7/76	47	12	0	0	0	0	18	0	0	
7/77	59	1	3	18	0	1	3	3	3	
8/77	13	13	13	13	13	13	0	0	13	
JULY	42	2	2	22	0	2	5	5	5	
AUG	7	4	2	2	2	4	0	70	2	
1977	61	2	2	14	0	2	2	2	5	
ALL	23	4	2	3	2	4	2	43	4	

Table 46. Percentages of energy demand of miscellaneous species occurring in water depth intervals.

RELATIVE EN ERGETIC DEMAND (% OF TOTAL FOR ALL IN TERVALS) FOR TOT

DEPTH (M)

	60	80	100	120	140	200	600	1400	.3000	ALL
8/75	15	11	3	4	12	4	21	19	10	
7/76	27	5	50	6	0	5	7	a	0	
7/77	49	4	2	5	15	4	11	4	5	
8/77	40	8	9	11	6	9	8	b	3	
JULY	40	4	15	6	13	4	10	4	4	
AUG	26	11	7	9	12	7	13	11	4	
1977	48	5	4	7	11	6	10	5	4	
ALL	37	7	12	7	11	5	11	7	4	

Table 47. Percentages of total community energy demand occurring in water depth intervals.

RELATIVE ENERGETIC DEMAND % OF TOTAL FOR ALL SPECIES) FOR FUL

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	≤	1	5	15	7	12	4	5	5	3
7/76	1	11	3	28	0	75	39	0	0	4
7/77	2	×	31	40	91	59	34	57	48	20
8/77	2	4	5	29	26	56	33	45	50	17
JULY	1	9	6	36	91	63	35	57	48	10
AUG	1	2	5	27	10	37	17	19	34	10
1977	2	6	16	33	80	57	34	51	49	19
ALL	1	5	6	31	48	46	27	29	38	10

Table 48. Percentages of total community energy demand contributed by fulmars in water depth intervals.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL SPECIES) FOR SHW

DEPTH (M)

	Go	80	100	120	140	200	600	1400	3000	ALL
8/75	5	51	46	19	54	42	11	52	81	34
7/76	0	1	0	0	0	0	0	0	0	0
7/77	0	2	7	6	0	3	5	8	19	2
8/77	0	6	1	1	4	2	2	3	9	3
JULY	N	2	1	4	0	3	5	8	19	1
AUG	3	30	11	4	45	20	7	35	34	19
1977	0	4	3	3	1	2	5	5	13	3
ALL	1	19	5	4	24	14	6	28	29	7

Table 49. Percentages of total community energy demand contributed by Shearwaters in water depth intervals.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL SPECIES FOR FTP

	DEPTH (M)									
	60	80	100	120	140	200	600	1400	3000	ALL
8/75	0	0	0	0	2	0	0	3	0	0
7/76	0	0	0	0	0	2	2	0	0	0
7/77	0	0	0	10	1	4	1	2	2	1
8/77	0	0	0	3	8	20	9	22	7	3
JULY	0	0	0	6	1	3	1	2	2	1
AUG	0	0	0	2	3	11	4	10	5	2
1977	0	0	0	6	2	12	3	12	5	2
ALL	0	0	0	4	2	8	2	8	3	1

Table 50. Percentages of total community energy demand contributed by Fork-tailed Storm-Pterels in water depth intervals.

RELATIVE EN FRGETIC DEMAND (% CF TOTAL FCR ALL SPECIES) FOR KWS

	DEPTH (M)									
	60	80	100	120	140	200	600	1400	3000	ALL
8/75	3	4	7	26	9	13	0	10	14	7
7/76	3	7	1	23	0	11	28	0	0	4
7/77	1	7	7	20	8	30	49	23	19	11
8/77	0	2	6	10	34	8	20	19	20	7
JULY	3	7	2	22	8	25	46	23	19	6
AUG	2	3	6	13	14	1a	12	13	18	7
1977	1	4	7	14	12	19	41	20	20	9
ALL	2	5	3	17	11	16	31	16	19	7

Table 51. Percentages of total community energy demand contributes by kittiwakes in water depth intervals.

RELATIVE ENERGETIC DEMAND % OF TOTAL FOR ALL SPECIES FOR MUR

	DEPTH (M)									
	60	80	100	120	140	200	600	1400	3000	ALL
8/75	89	42	35	37	28	29	78	1	0	52
7/76	88	73	96	41	0	5	28	0	0	86
7/77	93	79	46	12	1	2	9	8	10	62
8/77	96	86	86	56	26	13	36	11	11	68
JULY	89	76	91	24	1	3	12	8	10	77
AUG	91	61	74	53	27	20	60	5	6	60
1977	94	83	70	39	5	7	16	10	9	64
ALL	90	67	88	40	15	13	32	5	8	71

Table 52. Percentages of total community energy demand contributed by murres in water depth intervals.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL SPECIES) FOR AUK

	DEPTH (M)									
	60	80	100	120	140	200	600	1400	3000	ALL
8/75	0	1	2	0	0	0	0	0	0	0
7/76	6	4	0	4	0	0	0	0	0	5
7/77	0	1	2	1	0	0	0	0	0	0
8/77	2	1	1	1	0	0	0	0	0	1
JULY	5	2	0	2	0	0	0	0	0	3
AUG	1	1	2	0	0	0	0	0	0	0
1977	1	1	1	1	0	0	0	0	0	1
ALL	4	1	0	1	0	0	0	0	0	2

Table 53. Percentages of total community energy demand contributed by auklets in water depth intervals.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL SPECIES) FOR PUF

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	1	1	2	1	0	2	0	0	0	1
7/76	1	3	0	3	0	6	2	0	0	1
7/77	0	2	2	2	0	1	1	1	2	0
8/77	0	1	1	1	0	0	1	1	2	1
JULY	1	2	0	2	0	3	1	1	2	1
AUG	1	1	1	1	0	1	0	0	1	0
1977	0	1	1	1	0	1	1	1	1	1
ALL	1	1	0	1	0	2	1	0	1	1

Table 54. Percentages of total community energy demand contributed by puffins in water depth intervals.

RELATIVE ENERGETIC DEMAND (% OF TOTAL FOR ALL SPECIES) FOR MIS

DEPTH (M)

	60	80	100	120	140	200	600	1400	3000	ALL
8/75	1	1	2	1	0	4	0	27	0	3
7/76	1	1	0	0	0	0	1	0	0	0
7/77	3	1	4	9	0	1	1	2	2	3
8/77	0	1	1	1	1	1	0	0	2	1
JULY	2	1	0	6	0	1	1	2	2	1
AUG	1	1	1	1	0	2	0	18	1	2
1977	3	1	1	4	0	1	0	1	3	2
ALL	1	1	0	2	0	2	0	14	7	2

Table 55, Percentages of total community energy demand contributed by miscellaneous species in water depth intervals.

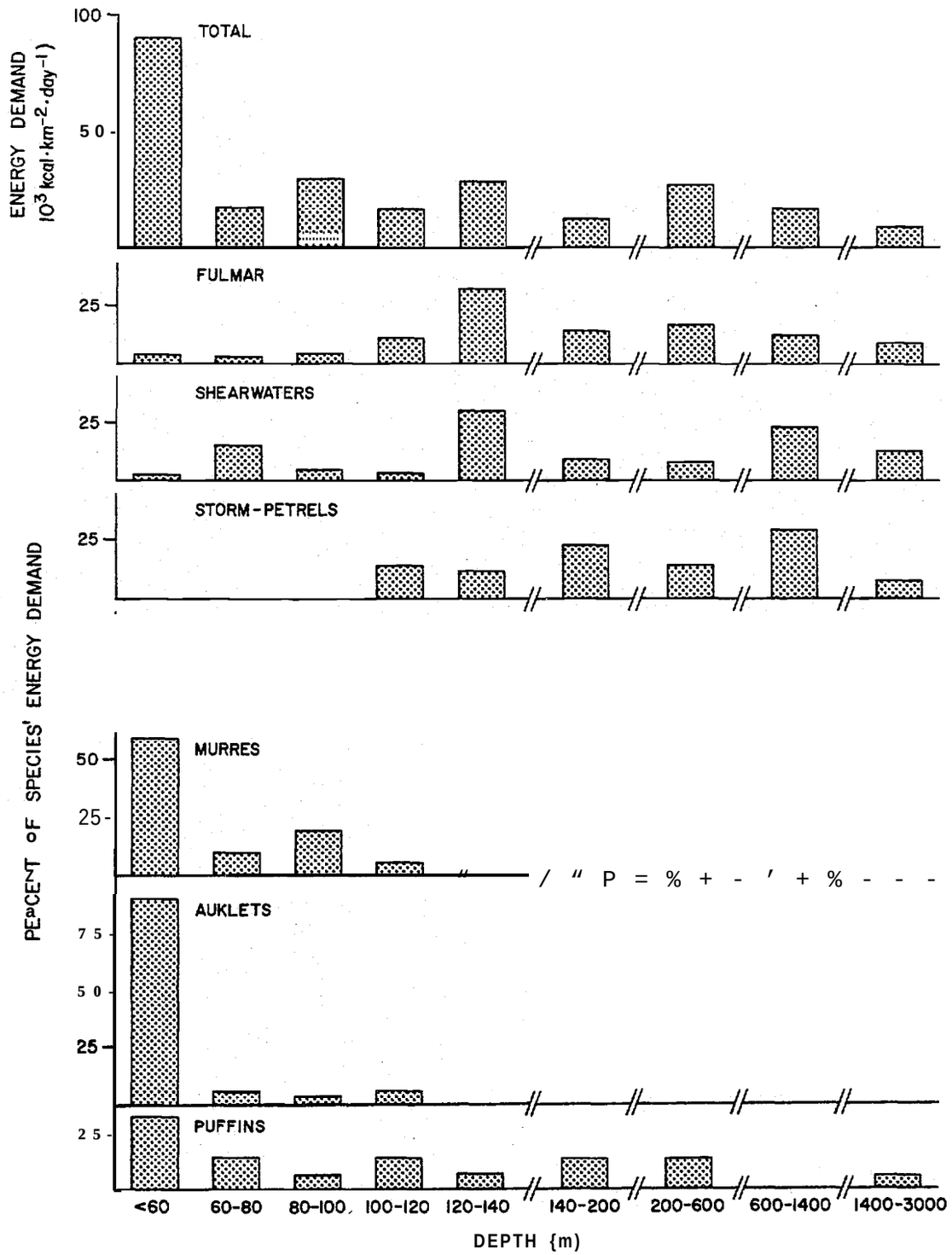

Fig. 6. Distribution of the energy demands of Pribilof Islands bird species or species groups. as a function of water depth. Data are derived from weighted averages of all transect censuses.

1975-77 seasons is indicated in Fig. 7. Data were combined for all censuses within 20′ blocks in order to permit us to generate continuous "contours" of species abundance and energy flow over this area. The frequency of occurrence for a given species within a 20′ block was calculated as the density of individuals within that block divided by the sum of that species' densities over all 20′ blocks. Contour surfaces were constructed by linear interpolation between grid block vertices using the Surface Display Library of the University of California (Berkeley) Computer Center. Interpolation was not carried out in the neighborhood of blocks for which there were no census data (5 blocks out of 56; Fig. 7). The resulting contour maps portray a probability surface in which the intervals define the Proportional distributions of all individuals recorded during censusing in the area as a whole. A similar procedure was used to determine contours of total community energy demand by 20′ blocks, using the calculated energy demands of species populations combined. Depth contours in this census area are shown in Fig. 8.

Over the intensive area shown in Fig. 7, murres accounted for 73.6% of the total energy flow through the collection of species populations considered in these analyses. The frequency of occurrence plotting (Fig. 9) shows that their distribution was heavily concentrated in the immediate vicinity of St. George, with two "peaks" of occurrence, southeast and southwest of the island. Although both of these "peaks" occurred in 80-100-m waters, the overall distribution of the birds, combined with the relatively small area of such depths (Fig. 8), led to an overall concentration of energy flow in shallower waters (Fig. 6). The decrease in frequency of occurrence of murres was sharper to the south of St. George, toward 'the shelf break, than to the north. In contrast, the birds associated with St. Paul were concentrated around the island in waters less than 60 m. and in an area to the east of the island in depths of 60-70 m.

The other alcids that we considered, auklets and puffins, contributed only 2.6% and 0.7% of the total assemblage energy demand, respectively. The spatial distribution of their occurrence, however, was basically similar to that of murres. Auklets exhibited a sharp localized association with St. George (80-100 m) and with St. Paul (less than 60 m; Fig. 10), while puffins, although showing the same foci, were much more widely scattered and were concentrated in depths of 60-80 m to the west of St. Paul (Fig. 11). Their distribution, however, was almost totally in shelf waters, extending primarily to the north of the islands. Possibly puffins, as a result of their abilities to return from foraging trips with several prey items, are less restricted in foraging flight distances from breeding colonies than are murres, which carry a single prey item per trip.

Fulmars contributed 9.3% of the total assemblage energy flow, and were rather diffusely distributed, with no strong association with the islands (Fig. 12). Their frequency of occurrence seemed greatest about and beyond the continental shelf break (100-1400 m) although the absence of censuses in the southwestern portion of the area (Fig. 7) weakens this conclusion. Kittiwakes (6.4% of the total community energetic) also showed a rather diffuse distributional pattern, but were somewhat more localized in the area to the south of St. George than the fulmars (Fig. 13). They were associated with the shelf break (200 m) south of St. George, but to the southwest of St. Paul they appeared to be concentrated in shallower waters. Kittiwakes

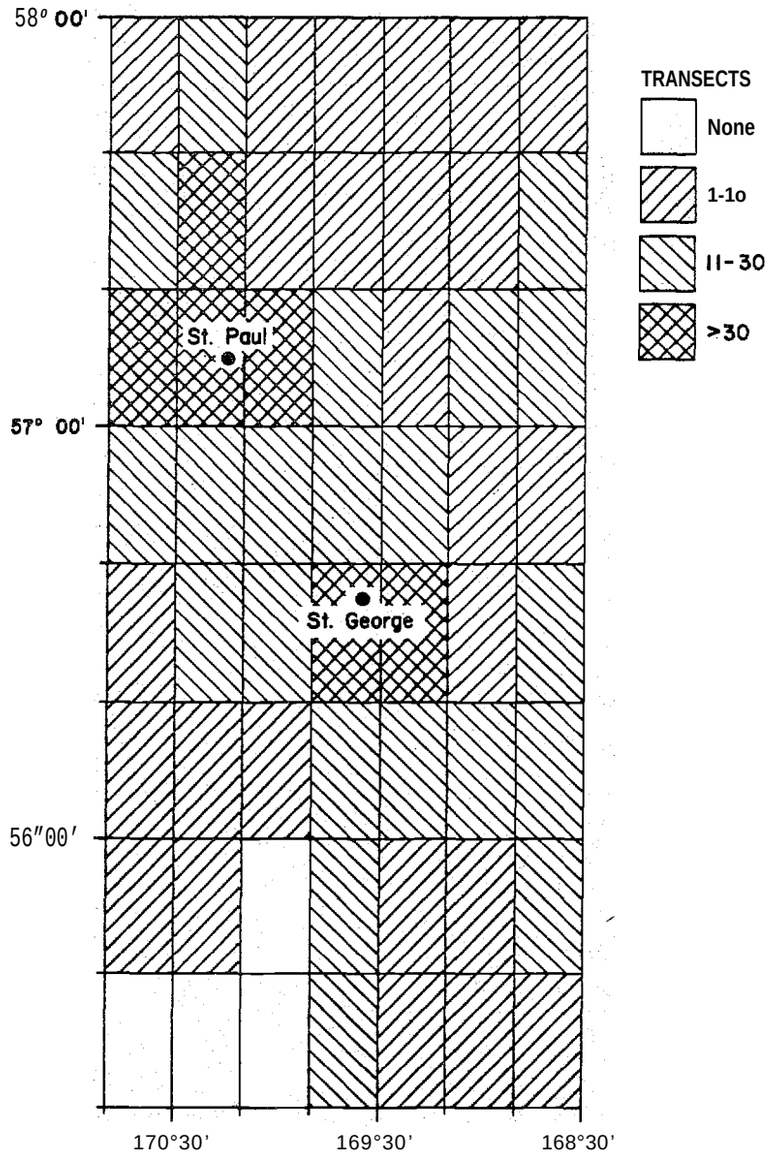

Fig. /. Intensity of transect censusing in 20′ blocks in the vicinity of St. George and St. Paul Selected 'or 'ntensive analysis of marine bird energetic. Shadings represent the number of transects conducted in a block during 1975-77 censusing.

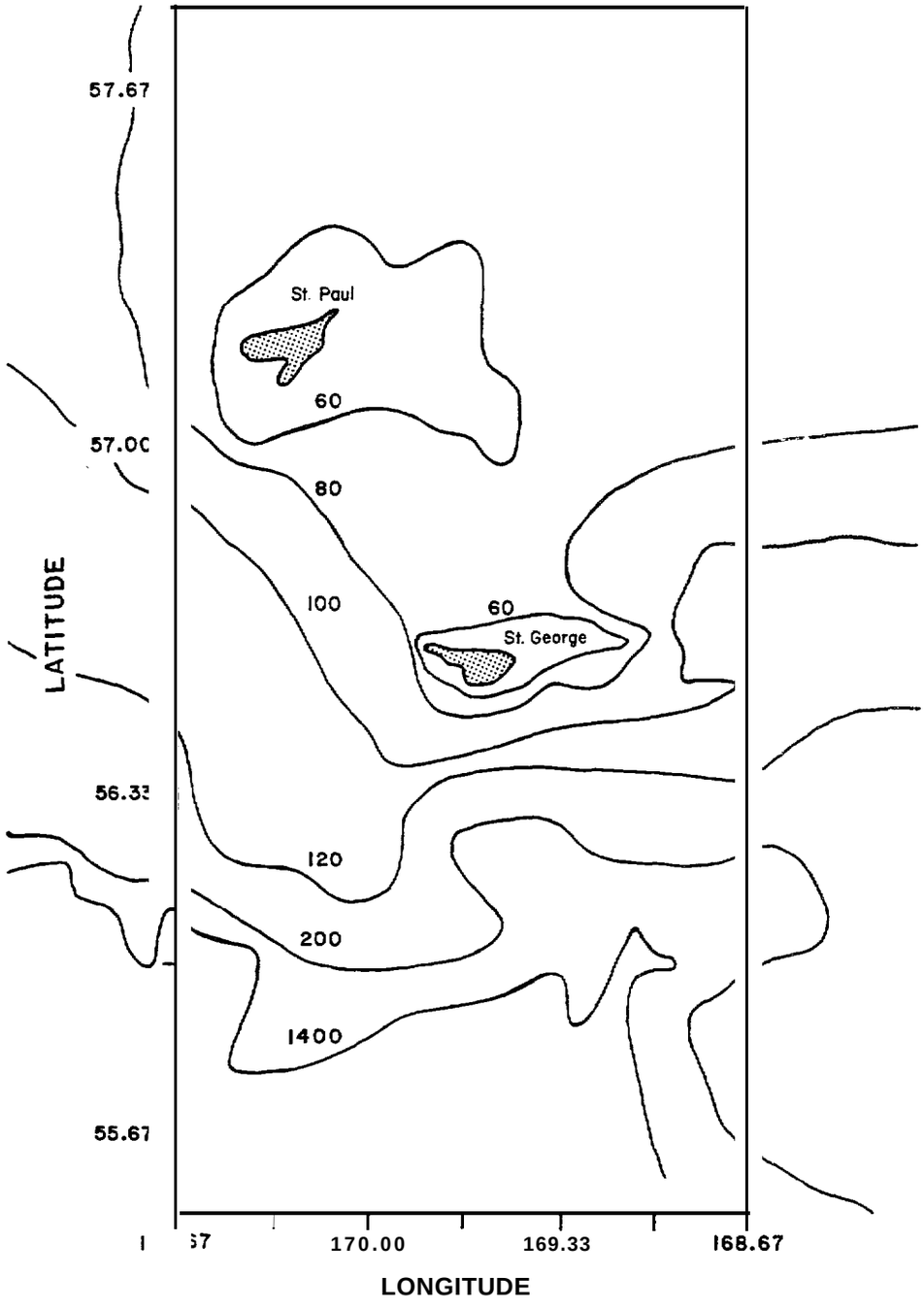

Fig. 8. Water depth contours in the vicinity of St. George and St. Paul, Pribilof Islands.

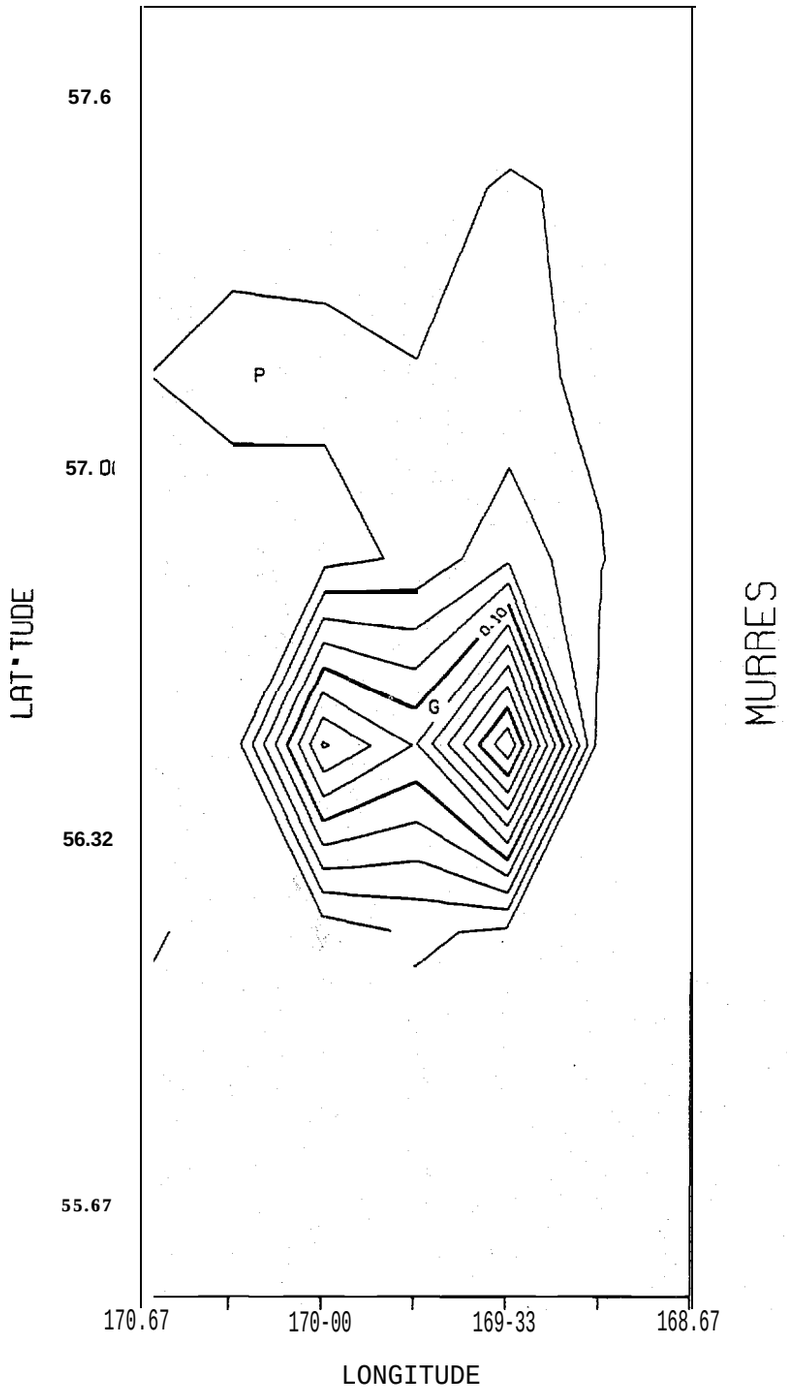

Fig. 9. Plottings of contours of frequency of occurrence of murres in the intensive analysis area of Fig. 7. Contour intervals (0.02) indicate the frequency of occurrence of the group in 20' blocks, as derived from weighted averages of transect censuses.

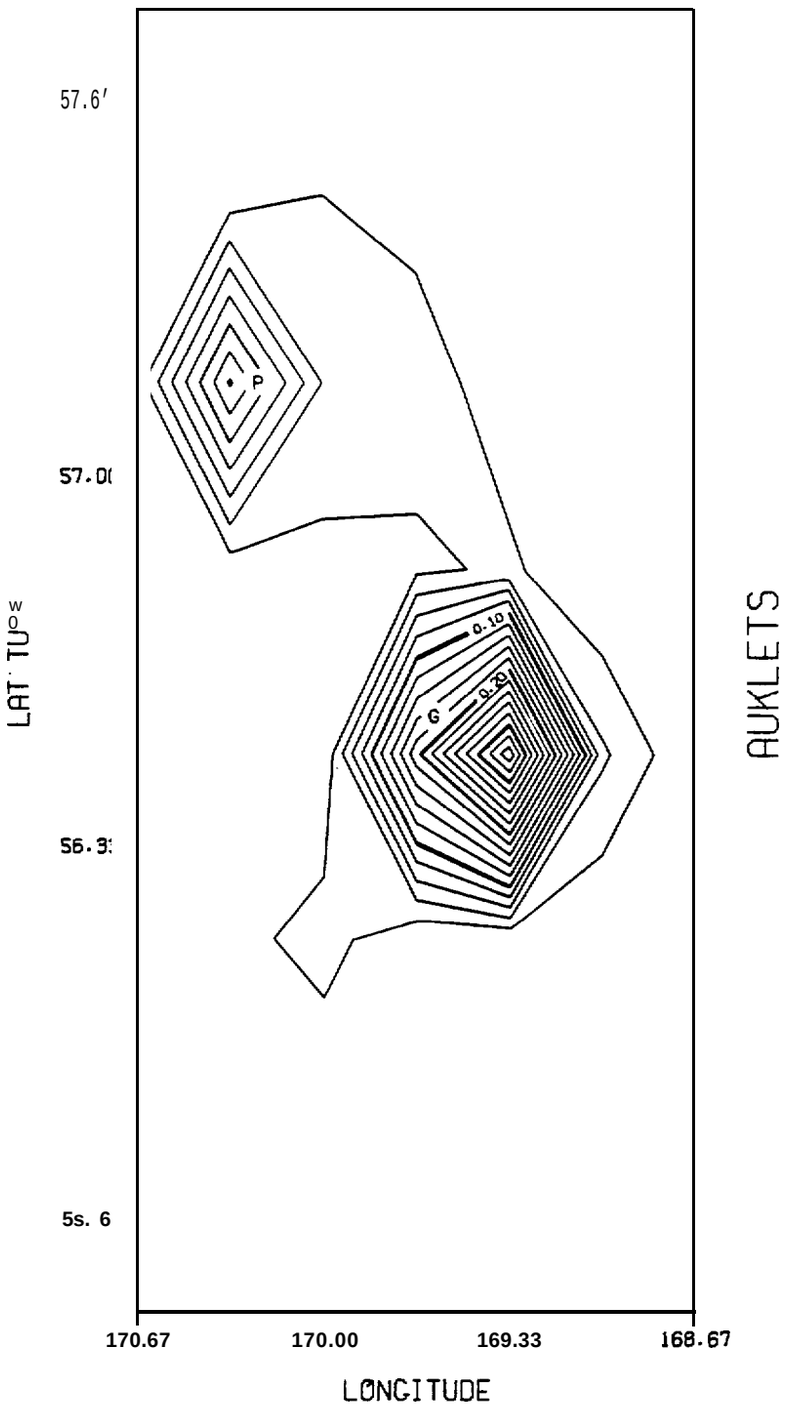

Fig. 10. Plottings of contours of frequency of occurrence of auklets in the intensive analysis area of Fig. 7. Contour interval 0.02; see Fig. 9.

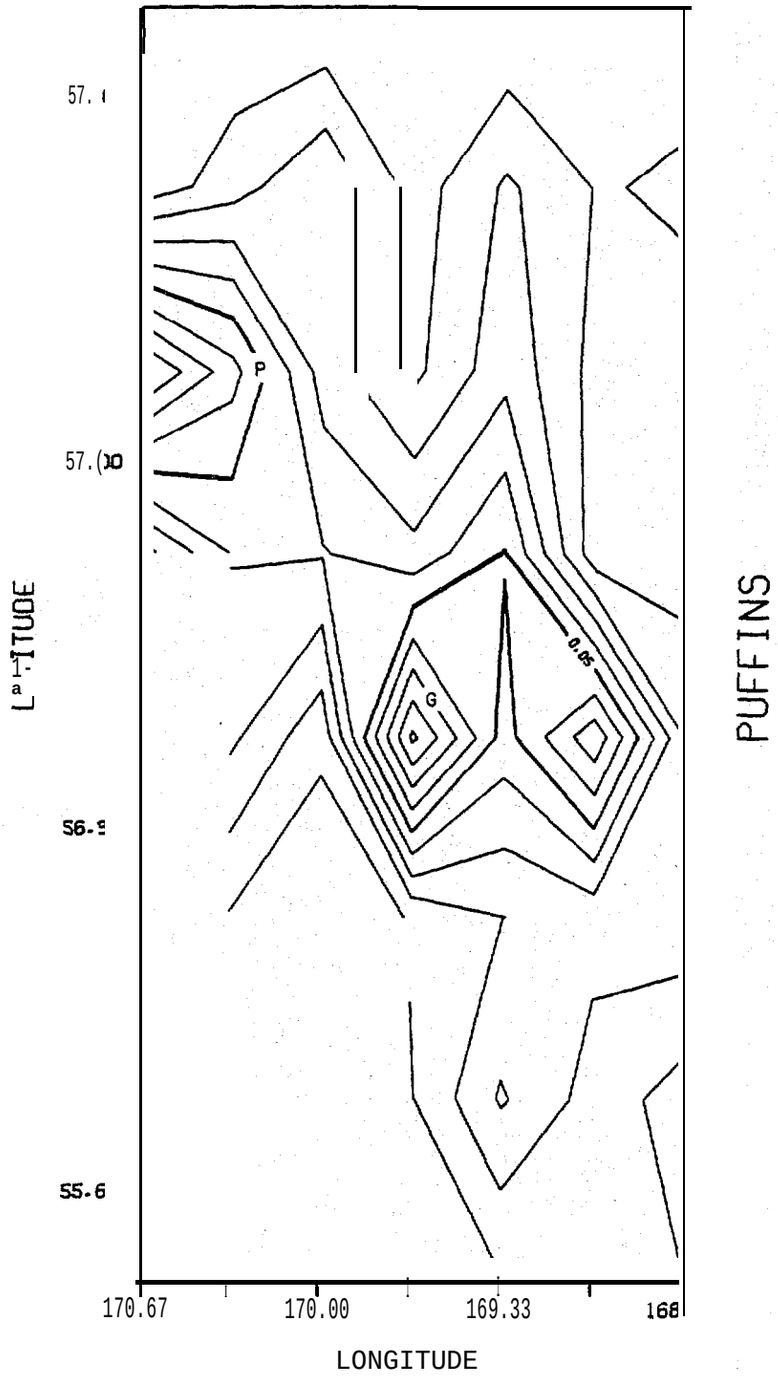

Fig. 11. Plottings of contours of frequency of occurrence of puffins in the intensive analysis area of Fig. 7. Contour interval 0. 01; see Fig. 9.

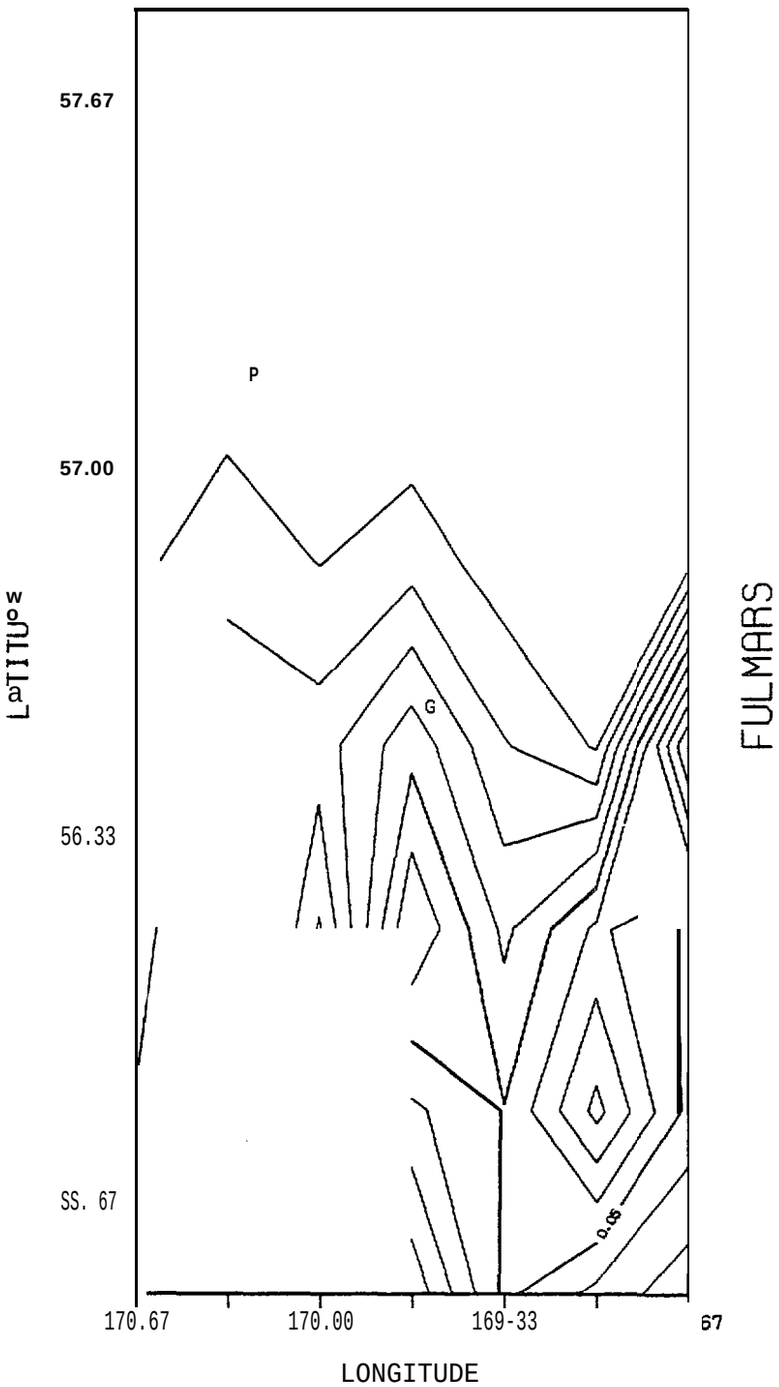

Fig. 12. Plottings of contours of frequency of occurrence of fulmars in the intensive analysis area of Fig. 7. Contour interval 0.01; see Fig. 9.

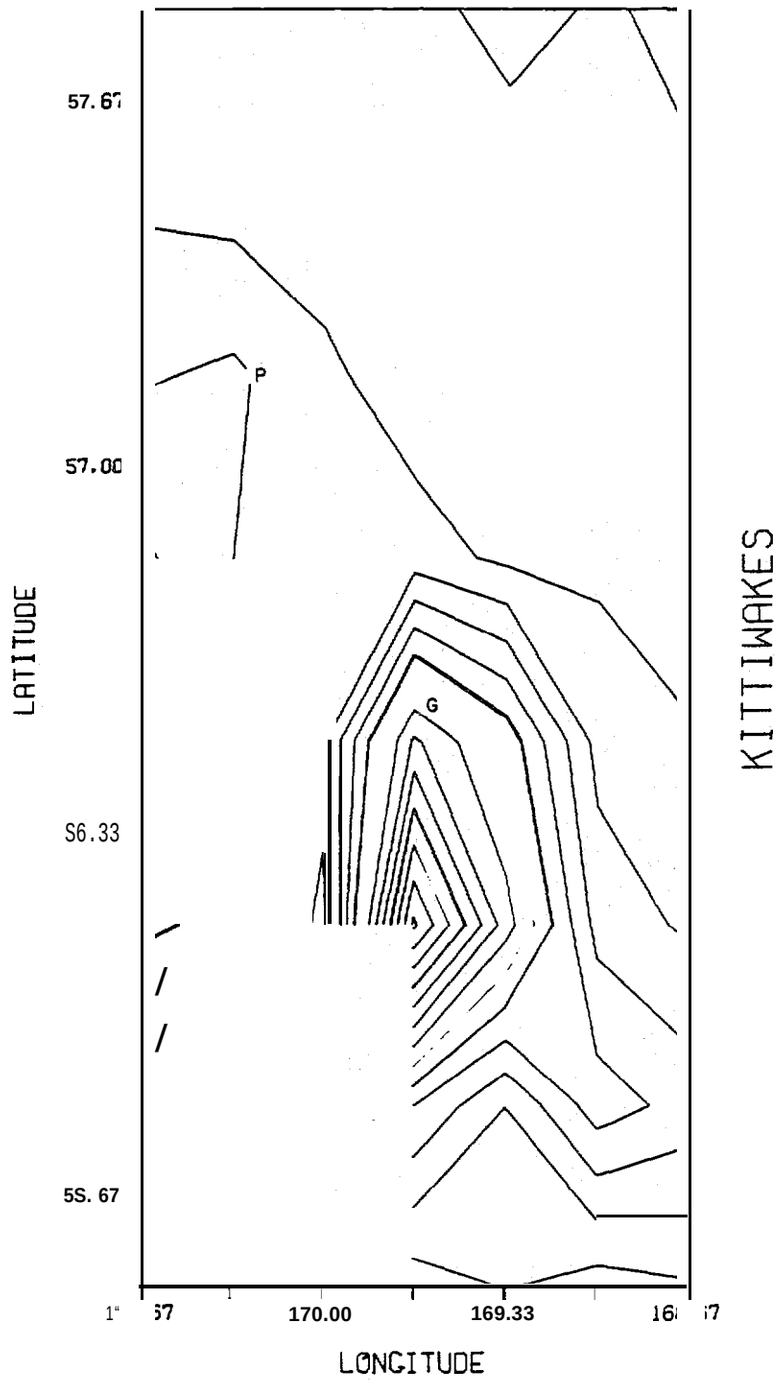

Fig. 13. Plottings of contours of frequency of occurrence of kittiwakes in the intensive analysis area of Fig. 7. Contour interval 0.01; see Fig, 9.

may be prohibited by distance from using the shelf break about St. Paul. The distance from St. Paul to the shelf break is roughly 100 km, while from St. George it is only 26 km.

Storm-petrels, accounting for 0.9% of the total energy flow, were most frequently encountered in censuses in the blocks to the southeast of St. George (Fig. 14), concentrating in waters of 100-1400 m depth along the shelf break. The spatial pattern of shearwater energy flow (6.6% of the aggregate total) is less reliable and clear than that of the other species because of the wide-ranging and erratic nature of large flocks and the fact that, unlike the other species, they do not breed on the islands. Two foci of abundance were apparent in the survey area, one in relatively shallow waters (60-100 m) directly west of St. Paul, the other along the shelf break to the southwest of St. George (Fig. 15). These patterns probably reflect the opportunistic nature of their foraging distribution.

The overall spatial distribution of total "community" energy flow (Fig. 16) not surprisingly parallels the occurrence of murres rather closely, it is apparent from this analysis that the major portion of the energy flow in the Pribilof Islands marine bird system is concentrated in the immediate vicinity of St. George, with a peak consumption rate of over 36,000 kcal km^{-2} day^{-1}.

V. CONCLUSIONS

While the analyses in this report must be regarded as preliminary estimations, they do serve to denote the "ball-park" of energy demands and their spatial distribution in two Alaskan oceanic areas. As the analyses are based upon transect censuses, they are subject to the various limitations that characterize the census techniques (Wiens et al 1978). In particular, the "communities" we have referred to are only partial characterizations of the total aggregate of bird populations present in these areas, although the major components are undoubtedly included. Further, the analysis implicitly assumed that the actual consumption of energy in a census block is a direct function of the bird densities recorded there; that is, we must assume that the birds are actually satisfying their daily energy demands in the same area in which they were recorded during censusing. This assumption is most likely to be violated in close proximity to islands, where a greater frequency of individuals flying back and forth between the colony and outlying feeding areas may be recorded. The concentration of energy flow about St. George that we have depicted (Fig. 16) may thus be somewhat overemphasized. In addition, the energy flows that we have calculated are undoubtedly underestimates, as no account has been made of the energy costs associated with foraging flights and rearing young for the breeding species. The next phase of our modeling efforts is designed to provide greater resolution of such spatial patterns of energy dynamics, as well as to include the energetic associated with breeding by the bird populations in the overall energy flow calculations.

We have been able to conduct a rather detailed assessment of the spatial distribution of energy flow in the Pribilofs largely because of the intensity of transect censusing in this area by Hunt and his colleagues. Still, there

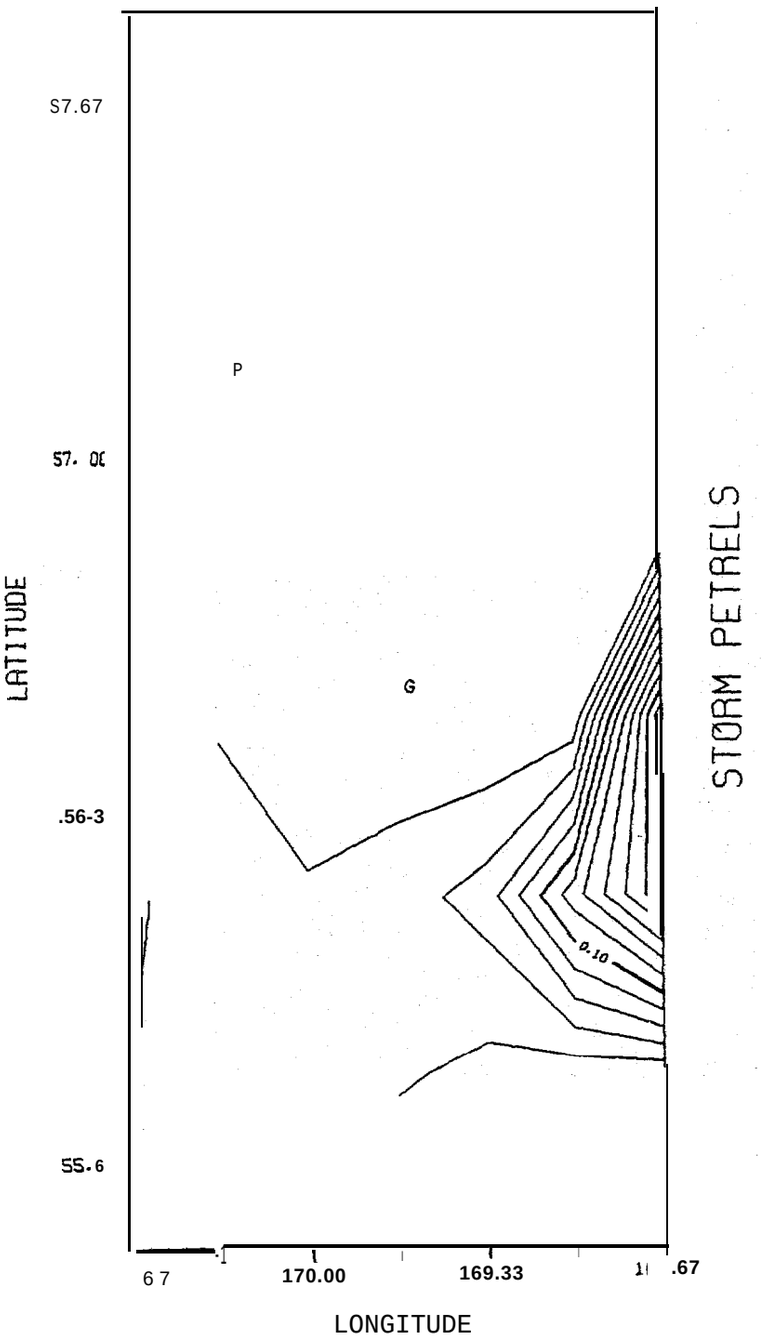

Fig. 14. Plottings of contours of frequency of occurrence of Fork-tailed Storm-Petrels in the intensive analysis area of Fig. 7. Contour interval 0.02; see Fig. 9.

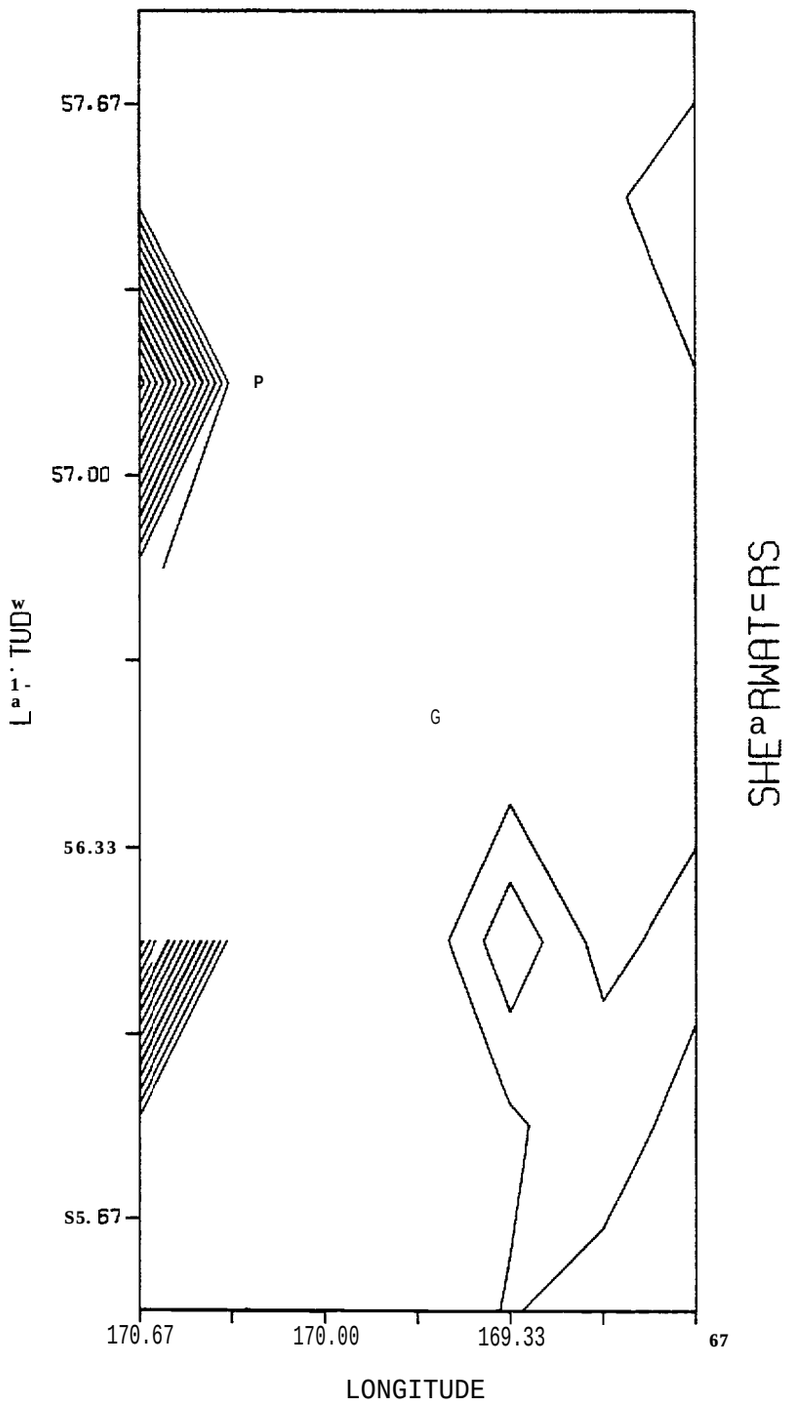

Fig. 15. Plottings of contours of frequency of occurrence of shearwaters in the intensive analysis area of Fig. 7. Contour interval 0.01; see Fig. 9.

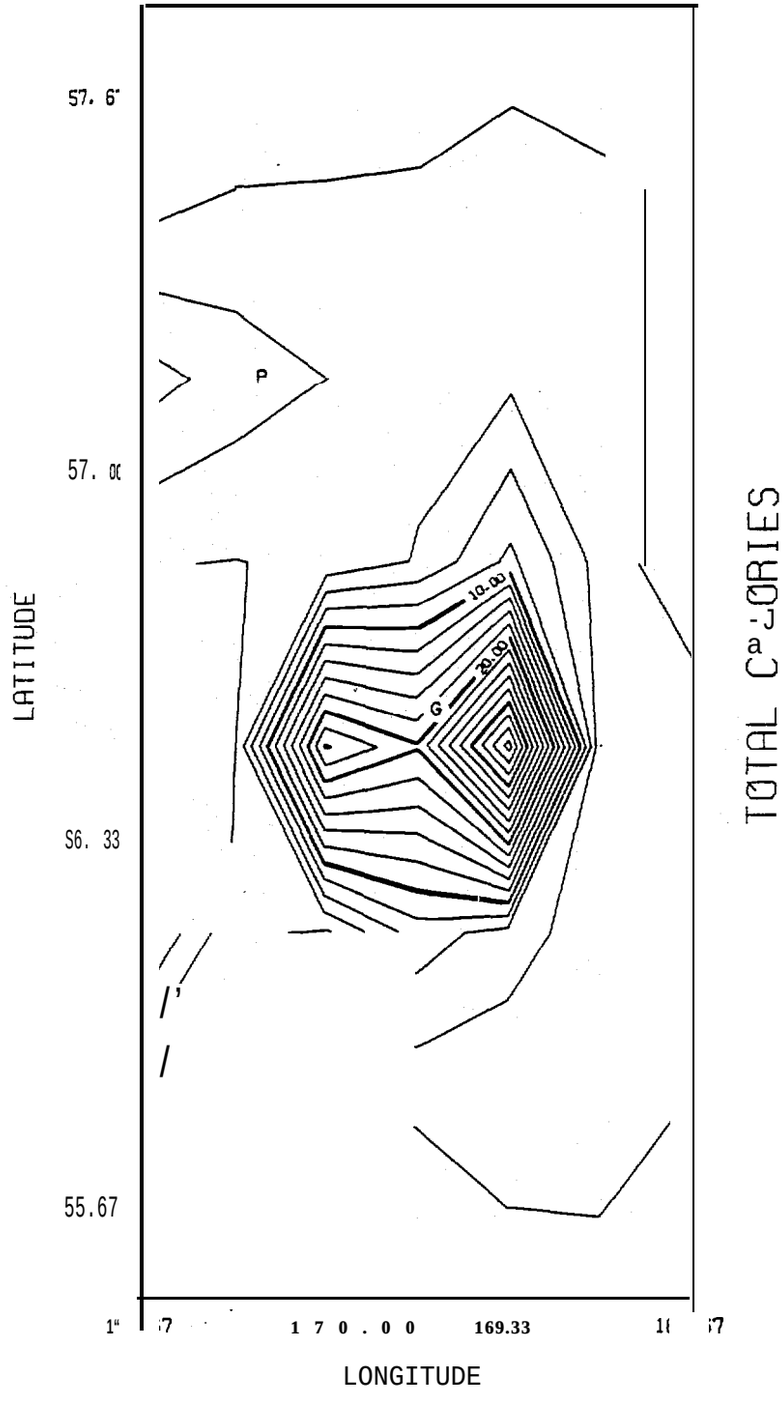

Fig. 16. Plotting of contours of total marine bird "community" energy demand for the intensive analysis area of Fig. 7.

are some important gaps in our resolution of the spatial distributional patterns, caused by inadequate censusing in some blocks, especially to the southwest of St. George (Figs. 3, 7). Steps should be taken to remedy this deficiency in future field studies.

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APPENDIX I: SCIENTIFIC NAMES OF BIRD SPECIES

Common Name	Scientific Name
Fulmar	*Fulmaris glacialis*
Sooty Shearwaters	*Puffinus griseus*
Short-tailed Shearwaters	*Puffinus tenuirostris*
Fork-tailed Storm-Petrel	*Oceanodroma furcata*
Glaucous-winged Gull	*Larus glaucescens*
Herring Gull	*Larus argentatus*
Black-legged Kittiwake	*Rissa tridactyla*
Arctic Tern	*Sterna paradisaea*
Common Murre	*Uris aalge*
Thick-billed Murre	*Uria lomvia*
Tufted Puffin	*Lunda cirrhata*
Homed Puffin	*Fratercula corniculata*