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Biomonitoring Using Least Terns and Black Skimmers in the Northeastern United States

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ABSTRACT

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Population sizes and reproductive success in colonies of least terns (*Sterna antillarum*) and black skimmers (*Rynchops niger*) were examined from Massachusetts to Cape May, New Jersey, to determine the utility of these species for monitoring population trends and environmental quality. Although some colonial species have been monitored for reproductive success, most schemes monitor only numbers of breeding birds or are more restricted geographically. For least terns in 1991, reproductive success was significantly lower on Long Island and higher in New Jersey. These differences persisted when compared with reference data from the previous 13–15 years for several of the same colonies that were relatively uncontaminated. There were no geographical differences in reproductive success in 1991 for black skimmers, although western Long Island productivity was below normal. The differences in reproductive success coupled with stable population numbers suggest that southern New Jersey may be providing excess young least terns and black skimmers that move into parts of New York with low reproductive success. Monitoring population numbers alone may not be adequately sensitive for management. Monitoring of productivity though more labor intensive allows the early identification of problem regions and temporal trends. Regional monitoring of reproductive success may be essential to determining the relative importance of protecting specific colonies, and for the early recognition of human impacts.

ADDITIONAL INDEX WORDS: *Coastal, birds, colonies, management, New York, New Jersey, monitoring, biomonitoring.*

INTRODUCTION

The utility of bird populations for biomonitoring environmental quality has been appreciated since the 1950's when birds provided CARSON (1962) and others with evidence of the impact of chemical contamination on environmental quality and ecosystem function. Although the earliest concern was for acute toxicity, studies on various raptors and fish-eating birds revealed that pollutants such as organochlorines and certain toxic metals bioaccumulated in avian tissues and produced chronic effects on individual survival and on reproduction (FURNESS and RAINBOW, 1990). Further, environmental quality includes habitat availability and degree of human disturbance as well as pollution.

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Biomonitoring, as opposed to direct environmental monitoring, employs organisms to provide information on the quality of the environment or on the status of particular contaminants. Sessile species like some bivalves provide information on a small spatial scale, while highly mobile species such as seabirds integrate exposure over much larger ranges. However, because many colonial species obtain food for their young in a restricted area within a few km of their colonies, the growth and survival of young birds can reflect the accumulation of pollutants from a single estuary.

Colonial seabirds often use the same breeding sites for years or decades (SOUTHERN, 1977; SOUTHERN and SOUTHERN, 1982), and they usually nest in inaccessible places where they are relatively safe from predators (LACK, 1968). Species that nest in ephemeral or vulnerable habitats shift locations frequently (McNicholl, 1975). Such species include the black-billed gull (*Larus bulleri*) which nests on sand bars in the middle of rivers (Beer, 1966), Franklin's gull (*L. pipixcan*) and brown-hooded gulls (*L. maculipennis*) which nest in prairie marshes (Burger, 1974a,b), and laughing gulls (*L. atricilla*) and certain terns (*Sterna* spp.) that shift colony sites under flood conditions (Montevecchi, 1978; Storey, 1987a,b; Burger and Gochfeld, 1991). These species face physical problems with their environments, but are usually not exposed to severe human disturbance.

Species that nest on coastal beaches not only face shifting habitat features, but are exposed to a variety of predators, whose populations are affected by people (*e.g.*, dogs, cats, rats, raccoons, foxes), direct human disturbance, and pollutants (Burger, 1984, 1989, 1991; Atwood and Massey, 1988; Burger and Gochfeld, 1990a,b). Beach nesting habitats are increasingly vulnerable to pollution and development, and many state and federal agencies have begun to monitor, protect, and enhance avian populations nesting on beaches.

Several pollutants have impaired the ability of certain species of birds to reproduce, and these species have subsequently sustained population declines (Ratcliffe, 1967; Peakall *et al.*, 1975). These avian reproductive impacts were detected long before impacts of these same pollutants were evident in other organisms in the ecosystem. These impacts should be assessed before populations decline as precipitously as did raptors and pelicans (*Pelecanus occidentalis*) in the 1960's (Hickey and Anderson, 1968; Hickey, 1969; Ratcliffe, 1972). Such anthropogenic impacts can be detected only through biomonitoring programs that periodically evaluate population sizes, reproductive success, and other adverse effects on individuals (*i.e.*, deformities, birth defects).

Most monitoring programs with birds only track population numbers and do not attempt to assess reproductive success. Yet estimates of reproductive success are essential to determine long-term population trends, the relative importance of particular colonies or populations, and whether given segments of the population are replacing themselves or are relying on other, nearby populations for recruitment. Long-term studies of population numbers and reproductive success are particularly critical (Nisbet, 1989). Increasingly, indices of reproductive success are useful for monitoring large regions (O'Connor and Dewling, 1986; Gilbertson *et al.*, 1991; Colborn, 1991).

In this paper, we examine colony size and reproductive success of least terns (*Sterna antillarum*) and black skimmers (*Rynchops niger*) nesting from Massachusetts to Cape May, New Jersey. Our overall objective was to examine whether there were subregional deficiencies in reproductive success that require further study of the causal agents, active management, imply anthropogenic or pollutant problems, or have implications for future population dynamics. We were particularly interested in whether there were significant differences among subregions. We test the null hypothesis that there were no differences in reproductive success among six subregions (Massachusetts, eastern Long Island, western Long Island, New York–New Jersey harbor estuary, northern New Jersey, southern New Jersey). Further, we compare our 1991 data to reference data from New Jersey (13–15 years per species, see Burger and Gochfeld, 1990a,b, 1991; Burger, 1990 for data set) to determine if reproductive success differed from mean reproductive success. For most species, there are no comparable long-term data on normal reproductive success making them less useful as indicator species.

With increasing interest in global patterns of environmental change, it is important to develop viable regional biomonitoring schemes to detect shifts in population sizes and reproductive success, and possible anthropogenic causes of such changes or declines. Most published surveys and censuses merely locate colonies and record population sizes (*i.e.*, Blokpoel and Harfenist, 1986). Similarly, large-scale coastal surveys that range from Maine to Florida report only colony sizes (Spendelow and Patton, 1988; Andrews, 1990). Although Massachusetts, New York, and New Jersey all monitor population sizes of least terns and black skimmers (Burger, 1990; Burger and Gochfeld, 1990a,b; Downer and Liebelt, 1989; Jenkins *et al.*, 1990; B. Blodgett, *unpublished data*), only New Jersey and Massachusetts monitor reproductive success. One of our objectives was to test the feasibility of a regional scheme for monitoring reproductive success.

STUDY AREA AND METHODS

We surveyed six colonies in Massachusetts (all colonies from the middle to the western tip of Cape Cod); *i.e.*, all colonies that were logistically accessible along the south shore of Long Island

and all colonies along the New Jersey shore for black skimmers and least terns. We divided the region into six subregions: Massachusetts, eastern Long Island (east of Islip), western Long Island, New York–New Jersey harbor estuary, northern New Jersey (north of Brigantine), and southern New Jersey. A summary of colonies examined is found in Table 1. Least terns nested in all six regions, but skimmers did not nest in Massachusetts and there was only one colony in the New York–New Jersey harbor estuary. We selected these regions because they are generally similar in size, and there are natural breaks in the distribution of colonies.

Our protocol was to survey and count the members in each colony (after KUSHLAN, 1986) every 7–10 days from 1 May until 31 July 1991, except when weather prevented access. Each of the six subregions had one or two observers assigned depending on the number of colonies. All observers were field-trained on our protocol and had previous experience with counting colonial and coastal birds. Inter-observer reliability was determined by Burger visiting four colonies with all observers and having all observers present (including Burger) estimate the number of flying adults, number of incubating adults, and later in the season, the number of flying young. An ANOVA indicated no significant variation among observers for the same colony.

On each visit the observer recorded colony, weather, number of adults present, number of nests, and number of flying young determined with binoculars from a vantage point at the edge of the colony. We entered most colonies only to make nest counts and to count clutch sizes to provide comparative data among areas.

For each colony, our methods resulted in weekly counts of the number of adults, number of pairs, and number of flying young. These same procedures had been employed for the reference colonies (BURGER, 1990). We had 2–7 clutch size counts for each colony. We selected one set of clutch size data to use for each colony by choosing the data set having the largest number of nests with the optimal or maximum clutch size (*e.g.*, 2 eggs for least tern, 3–4 eggs for skimmers). Our methods required one to two full-time field assistants in each subregion from 1 May until mid- to late August.

For reproductive success, we inspected the weekly counts, selecting the greatest number of pairs (or nests) to use for the colony size. We determined the total number of fledglings by finding the date with the greatest number of flying young, and adding this estimate of the number of flying young to the number of flying young observed two weeks before and two weeks after. This is necessary because young usually leave the colony area after 10–12 days (THOMPSON and SLACK, 1984). Although this system is not perfect, it gives a more realistic index of the number of young fledged than using only the maximum number of flying young on any one date.

Table 1. *Regions studied and number of colonies followed in each habitat for least tern and black skimmer in 1991.*

Species	Region	Sand or Gravel	Salt Marsh
Least tern	Massachusetts	5	0
	Eastern Long Island	16	0
	Western Long Island	11	0
	NY–NJ Harbor estuary	4	0
	Northern New Jersey	35	0
	Southern New Jersey	6	0
Black skimmer	Eastern Long Island	3	0
	Western Long Island	4	2
	Northern New Jersey	2	9
	Southern New Jersey	3	0

Reproductive success in each colony thus equals the number of fledglings divided by the number of nests (or pairs). This is a conservative measure because not all fledglings are visible and some fledglings may leave the colony before being counted. This methodology has been followed in New Jersey for several years as part of a state monitoring plan (BURGER, 1990; BURGER and GOCHFELD, 1990a), and has provided an index of reproductive success.

We compared 1991 reproductive success among regions using an ANOVA followed by a Tukey's test, a multiple comparisons test (ZAR, 1984). We used 13–15 years of data on reproductive success from 10–20 colonies in New Jersey (BURGER, 1990; BURGER and GOCHFELD, 1990b, 1991) to determine normal reproductive success. We then used student's t test to compare the 1991 data with the reference populations to determine if they differed significantly.

RESULTS AND DISCUSSION

Biomonitoring Scheme

For both species, there were no significant subregional differences in clutch size (ANOVA for terns, $F = 2.34$, $df = 5,35$; for skimmers, $F = 0.14$,

Table 2. *Comparison of regional reproductive success with past data (mean ± SE).*

Region	Number of Colonies	Total Estimated Number Nests	Mean Clutch Size ± SE	Total Number Chicks Fledged	Reproductive Success: Weighted Mean[a]	Reproductive Success: Mean (±SE)	Comparison with Reference Population t (p)
Least tern							
Massachusetts	5	390	2.08 ± 0.18	171	0.43	0.63 ± 0.0	0.50 (NS)
Eastern Long Island	16	834	1.88 ± 0.18	86	0.10	0.14 ± 0.01	2.93 (0.005)
Western Long Island	11	640	1.78 ± 0.13	165	0.24	0.27 ± 0.03	1.61 (0.05)
NY–NJ Harbor estuary	3	110	1.85 ± 0.03	38	0.34	0.22 ± 0.08	1.02 (NS)
Northern New Jersey	5	796	1.89 ± 0.08	646	0.80	0.96 ± 0.07	1.97 (0.02)
Southern New Jersey	6	302	1.86 ± 0.06	296	0.98	1.09 ± 0.14	2.70 (0.005)
Black skimmer							
Eastern Long Island	3	39	2.63 ± 0.73	36	0.92	0.40 ± 0.23	0.71 (NS)
Western Long Island	4	238	2.81 ± 0.45	191	0.80	0.22 ± 0.10	1.49 (0.10)
Northern New Jersey	11	381	2.82 ± 0.38	174	0.46	0.56 ± 0.04	0.63 (NS)
Southern New Jersey	3	364	2.70 ± 0.46	408	0.85	1.02 ± 0.01	0.81 (NS)

[a]Weighted mean = total number of fledged chicks/total number of nests for each region

df = 3,16; Table 2). Reproductive success in least terns varied from 0 to 1.50 young fledged per pair in the different colonies. There were significant subregional differences (F = 7.2, df = 5,45, P < 0.001; Tables 2 and 3). Reproductive success in black skimmers ranged from 0 to 1.25 young fledged per pair, but there were no significant subregional differences (F = 1.7, df = 3.18, P = 0.2; Tables 2 and 3). The primary causes of reproductive failure observed were storms, human disturbance and predators, although in some cases the causes were not obvious.

Comparing the 1991 reproductive success data with the reference data set (BURGER, 1990; BURGER and GOCHFELD, 1990a) indicated several significant differences (Table 3). For least terns, reproductive success was significantly higher in New Jersey and significantly lower on Long Island. The New York–New Jersey harbor colonies were all on Sandy Hook, New Jersey. Reproductive success for black skimmers did not differ significantly from the reference population except for western Long Island with marginally lower reproductive success (0.10; Table 3). Overall, low productivity suggests problems from Massachusetts to the New York–New Jersey harbor for these two beach-nesting species.

Methodological Considerations

There are several potential biases in survey and census work that is conducted over a large geographical region: (1) observer bias, (2) selection of colonies to monitor, and (3) methods of determining reproductive success. Observer bias can occur if there is a lack of agreement in observer estimates of the number of birds on the ground or flying above the colony, or if one observer consistently over- or underestimates the number of fledglings or adults. We reduced this source of error by using only experienced observers, training the observers to the same field protocol, and running trials where several observers counted birds simultaneously in several colonies to determine inter-observer reliability.

Table 3. *Comparisons of reproductive success among subregions in 1991 for least terns above diagonal, skimmers below diagonal. Given are Tukey critical values (after Zar, 1984) and probability levels (NS = not significant, NA = not applicable).*

	Massachusetts	Eastern Long Island	Western Long Island	NY–NJ Harbor	Central New Jersey	Southern New Jersey
Massachusetts		3.3 (NS)	2.3 (NS)	2.0 (NS)	1.8 (NS)	2.6 (NS)
Eastern Long Island	(NA)		1.1 (NS)	0.4 (NS)	5.6 (0.01)	6.9 (0.001)
Western Long Island	(NA)	(NA)		0.3 (NS)	4.5 (0.03)	5.6 (0.01)
NY–NJ Harbor	(NA)	(NA)	(NA)		3.6 (NS)	4.3 (0.05)
Northern New Jersey	(NA)	(NA)	4.0 (0.01)	(NA)		0.7 (NS)
Southern New Jersey	(NA)	(NA)	4.2 (0.01)	(NA)	3.6 (NS)	

Considerable attention has been devoted to methods of counting seabirds, both at sea and on the breeding grounds. These studies seem to indicate that the best estimates are obtained from the highest point or transect along the colony edge immediately upon arrival (DAWSON, 1981; HANSSEN, 1982), and with more rather than fewer counts per colony (STOWE, 1981). Estimates of within ±10% were considered reliable (HANSSEN, 1982). Most of these studies involved species that nest in heterogeneous environments with obstructions such as low vegetation, trees, or rocks. Most of the habitats we studied were flat, open, unobstructed sand beaches or islands, which facilitated visual estimates and contributed to our low inter-observer variability. Further, when colonies were undisturbed, skimmers and terns continued to incubate and could be counted while they remained incubating.

Selection of colonies to monitor is a potential problem if colonies selected are not representative of the population as a whole. Potential biases also occur where only the large, stable colonies are monitored and smaller, ephemeral colonies are ignored. For this reason, we designed our study of least terns and black skimmers to include *all* the colonies from Montauk south along Long Island's south shore to the New York harbor, and along the entire Atlantic coast of New Jersey. Only one or two least tern colonies on the south shore of Long Island were not surveyed because it was logistically impossible to reach them on a regular basis. In 1991, there was no significant correlation between number of nests (*i.e.,* colony size) and reproductive success for either least terns or black skimmers.

One reason to monitor all colonies within the study area is that beach-nesting birds shift colony sites when shore erosion occurs due to storms and winter tides. Even so, least terns often nest in the same general area year after year (BURGER, 1984; ATWOOD and MASSEY, 1988). Because major colony shifts can occur, it is difficult to select a sampling regime prior to initiation of nesting. Sampling all colonies of least terns and black skimmers eliminates the need to select and provides an estimate of the whole population.

In these migratory species, the food they are able to acquire in the few weeks between arrival and egg-laying determines the number and quality of the eggs they lay (NISBET, 1973). Pollutants that accumulate in the eggs are largely derived from this recently acquired food, supplemented by circulating pollutants recently mobilized from fat stores depleted during migration (OSBORN, 1979; GOEDE and DE BRUIN, 1984).

Table 4. *Estimating reproductive success by two methods at Brigantine Beach and Barnegat Inlet, New Jersey (1981–1983).*

	Number of Nests		Reproductive Success	
	Nest Checks[b]	Colony Checks[a]	Nest Checks[b]	Colony Checks[a]
Least terns				
Barnegat Inlet				
1981	51	48	0.35	0.30
1982	26	25	0.57	0.60
1983	9	10	0.44	0.40
Brigantine Beach				
1981	78	75	0.41	0.40
1982	143	140	1.25	1.32
1983	282	275	0.61	0.56
Black skimmer colonies (1979)				
Marshilder	82	82	0	0
Mordecaei	44	51	0.25	0.25
West Ham	27	27	1.21	1.19
Cedar Bonnet	13	13	0.76	0.76
West Carvel	14	14	0.86	0.86

[a]After BURGER (1980–1990), BURGER (1982, 1984, 1989)
[b]After BURGER and GOCHFELD (1990), BURGER (unpublished)

Reproductive success can be determined in several ways. Following the fate of a subsample of fenced nests from laying to fledging gives detailed estimates but is invasive and labor intensive (NISBET and DRURY, 1972). Following individually marked clutches and young is intermediate in effect. Estimating overall reproductive success of the colony by dividing the number of fledged young by the number of pairs nesting in the colony (as in this study) causes the least disturbance and yields results comparable to other estimates and from area to area (DAWSON, 1981; HANSSEN, 1982). Early in the development of this methodology, Burger employed a full-time field assistant to monitor individual nests of least terns at Brigantine Beach for three years (1981–1983), and simultaneously followed the census procedures outlined in this study. Similarly, four skimmer colonies were studied intensively (individual nests followed) and extensively (colony surveys) in 1979. Overall, taking a detailed census of individual nests resulted in slightly higher estimates of reproductive success, and the results were similar from year to year (Table 4).

Following the success of individual nests that are fenced has the advantage of providing estimates of individual success with a variance, whereas our method does not provide an estimate of variance for each colony. However, following success in individual nests is more labor intensive and requires periodic entrance into the colony which can cause reproductive losses (MOUSSEAU, 1984), particularly in least terns and black skimmers (SAFINA and BURGER, 1983).

Determining reproductive success for the entire colony has the disadvantage of not following individual pairs. It tends to underestimate reproductive success because some young leave the colony undetected between censuses or are away from the colony during a census. Nonetheless, least terns and black skimmers nest in open beaches with high visibility; and with patience, the number of nesting pairs and fledged young (on the ground and flying) can be accurately counted. The resultant index of reproductive success is comparable from colony to colony and does not result in losses due to human disturbance.

Cost effectiveness is an important criterion for most biomonitoring schemes (NRC, 1990). We found that monitoring a region using the colony index (estimates of the number of fledged young per pair) required one to two field assistants per subregion, or about nine for the entire region. If we had used the more labor-intensive method of fencing or following reproductive success in individual nests, we would have required additional personnel. We estimated that at least 25 field personnel would have been needed to achieve the same coverage. Since the major costs of such a study are field personnel time, travel, and housing, the overall cost of a more intensive monitoring program would be at least three times as expensive for little improvement in our measures of reproductive success.

Differences in Reproductive Success Within the Region

The census data for 1991 indicated that similar numbers of least terns and black skimmers bred along the south shore of Long Island (DOWNER and LIEBELT, 1989) and coastal New Jersey (BURGER, 1990) as in previous years. Thus in the short-term, the breeding populations have remained relatively stable.

Clutch size is an important component of the reproductive cycle because it directly affects reproductive success in any breeding season, and ultimately affects the lifetime fitness of any individual female. The factors affecting clutch size are geographical (latitude, longitude, altitude), demographic (age structure), ecological (population density, habitat), and inter-year–seasonal food availability (LACK, 1968; KLOMP, 1970; HUSSELL, 1972; MURRAY, 1979; RYDER, 1980). Age affects clutch size; mature adults have larger clutches than younger or aged parents (RYDER, 1980; NISBET *et al.*, 1984). Thus, differences in clutch size could reflect population age structure differences and, ultimately, the quality of parents. Older and more experienced parents generally have higher reproductive success (COULSON, 1966; RYDER, 1980).

Furthermore, differences in the availability and quality of food can affect clutch size. MURRAY (1985) predicted that food availability preceding the egg-laying period may be the proximate cue by which birds reduce their clutch size and reproductive risk. There are yearly variations in food supply that affect the populations we studied (SAFINA and BURGER, 1988).

Thus regional differences in clutch size could reflect differences in age structure or food availability, which in turn could account for regional differences in reproductive success. Clutch size variation can cause reproductive success to vary, even when the same percentage of eggs results in fledged chicks. The converse is not necessarily true; that is, a lack of difference in clutch size does not indicate a lack of difference in age structure or food availability among regions. Nonetheless, the lack of a significant difference in clutch size among regions for least terns and black skimmers indicates no gross differences in food supply or parental quality, and that observed differences in reproductive success were not due to initial clutch size differences.

We found subregional differences in reproductive success. The pattern was similar for least terns and black skimmers that often nest together on sandy beaches (refer to Tables 2 and 3). Reproductive success was significantly lower in parts of Long Island and significantly higher in southern New Jersey. These findings focus attention on possible causes of the differences, and on the implications for future population dynamics of the region. Furthermore, reproductive success for both species was significantly lower than normal in some subregions as determined from the 13–15 year data set for the reference colonies. Taken altogether, these indicators suggest reproductive problems for the Massachusetts to New York–New Jersey harbor area.

Causes for lowered reproductive success in beach-nesting birds include predators, weather (storms and hurricanes, tides and flooding; BURGER and GOCHFELD, 1991). Under some circumstances, any of these factors can cause total failure of a breeding colony. Failure can result in either colony desertion or massive re-nesting (BURGER and GOCHFELD, 1991). Anthropogenic causes of reproductive losses include direct human disturbance (people in colonies, off-road vehicles, dogs), habitat losses, and pollutants of one kind or another (PEAKALL, 1992). The extent of habitat loss and human disturbance is easy to observe, but the effect of pollutants is difficult to determine when the effects are sub-lethal.

Coastal colonial species presumably evolved with the natural forces of storms, high tides, and natural predators, and their populations can withstand them (BURGER and GOCHFELD, 1990a). However, adding the costs of increased predator numbers, human disturbance, and pollutants may reduce reproductive success to non-sustainable levels.

Utility for Biomonitoring

The effects of pollutants on avian reproduction are impossible to evaluate without additional study of pollutant levels in these species throughout the region. However, in the past, mercury, PCB's and DDT have been implicated in developmental defects in terns from New York (HAYS and RISEBROUGH, 1972; GOCHFELD, 1975, 1980) that resulted in lowered reproductive success. This study provides a cost-effective approach to monitoring productivity, which in turn can be used as an early warning signal before massive reproductive failures, deformities, or mortalities occur.

The implications of different rates of reproductive success within the region include: potential population declines in the future in some parts of the region with increases in others; stable regional populations with some sections contributing recruits to areas with low reproductive success; abandonment of places with low reproductive success; and consolidation of colonies into areas with high reproductive success. The monitoring data will indicate reproductive impairment and population trends. They can point to areas where further study including chemical analyses are warranted.

If the results of our reproductive estimates are representative of past years in the Montauk to Cape May coastal region, then reproductive success is sufficiently low in eastern Long Island (least terns), western Long Island (least terns and skimmers), and the New York–New Jersey harbor estuary (least terns), to suggest that populations will not remain stable without new recruits from elsewhere. The relatively high production in parts of New Jersey suggests that these colonies may be providing the recruits, and banding studies have documented some interchange among subregions (BURGER and GOCHFELD, 1991).

One other consequence of low productivity is colony abandonment and subsequent movement to other, more productive colonies. BURGER (1982) reported that skimmers do shift sites when they have suffered low reproductive success. If these shifts continue, then regional populations may consolidate into a few, large colonies located on relatively safe nesting sites. This consolidation appears to have happened in New Jersey where there are fewer, but larger least tern colonies than New York (BURGER, 1990). A loss of colony diversity is disadvantageous because it increases the risk of catastrophic or pollution events affecting a large segment of the population.

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LITERATURE CITED

ANDREWS, R. (Compiler), 1990. *Coastal Waterbird Colonies: Maine to Virginia 1984–85, Part I and II*. Newton Corner, Massachusetts: U.S. Fish and Wildlife Service, 807p.

ATWOOD, J.L. and MASSEY, B.W., 1988. Site fidelity of least terns in California. *Condor*, 90, 389–394.

BEER, C.G., 1966. Adaptations to nesting habitat in the reproductive behaviour of the black-billed gull *Larus bulleri*. *Ibis*, 108, 394–410.

BLOKPOEL, H. and HARFENIST, A., 1986. Comparison of 1980 and 1984 inventories of common tern, Caspian tern and double-crested cormorant colonies in the Eastern North Channel, Lake Huron, Ontario, Canada. *Colonial Waterbirds*, 9, 61–67.

BURGER, J., 1974a. Breeding adaptations of Franklin's gull (*Larus pipixcan*) to a marsh habitat. *Animal Behavior*, 22, 521–567.

BURGER, J., 1974b. Breeding biology and ecology of the brown-hooded gull in Argentina. *Auk*, 91, 601–613.

BURGER, J., 1982. The role of reproductive success in colony-site selection and abandonment in black skimmers (*Rynchops niger*). *Auk*, 99, 109–115.

BURGER, J., 1984. Colony stability in least terns. *Condor*, 86, 61–67.

BURGER, J., 1989. Least tern populations in coastal New Jersey: Monitoring and management of a regionally-endangered species. *Journal of Coastal Research*, 5, 801–811.

BURGER, J., 1990. *Least tern and black skimmer survey report*, 1990. (Unpublished report) Trenton, New Jersey: New Jersey Department of Environmental Protection, 16p.

BURGER, J., 1991. Coastal landscapes, coastal colonies, and seabirds. *Reviews in Aquatic Sciences*, 4, 23–43.

BURGER, J. and GOCHFELD, M., 1990a. *The Black Skimmer: Social Dynamics of a Colonial Species*. New York: Columbia University Press, 355p.

BURGER, J. and GOCHFELD, M., 1990b. Nest site selection in least terns (*Sterna antillarum*) in New Jersey and New York. *Colonial Waterbirds*, 13, 31–40.

BURGER, J. and GOCHFELD, M., 1991. *The Common Tern: Its Breeding Biology and Social Behavior*. New York: Columbia University Press, 413p.

CARSON, R., 1962. *Silent Spring*. Boston: Houghton Mifflin, 368p.

COLBORN, T., 1991. Epidemiology of Great Lakes bald eagles. *Journal of Toxicology and Environmental Health*, 33, 395–453.

COULSON, J.C., 1966. The influence of pair-bond and age on the breeding biology of the Kittiwake gull, *Rissa tridactyla*. *Journal Animal Ecology*, 35, 269–279.

DAWSON, D.G., 1981. Experimental design when counting birds. *Studies in Avian Biology*, 6, 392–398.

DOWNER, R.H.L. and LIEBELT, C.E., 1989. *1989 Long Island Colonial Waterbird and Piping Plover Survey*. Stonybrook, New York: New York Department of Environmental Conservation, 201p.

FURNESS, R.W. and RAINBOW, P.S., 1990. *Heavy Metals in the Marine Environment*. Boca Raton, Florida: CRC Press.

GILBERTSON, M.; KUBIAK, T.; LUDWIG, J., and FOX, G., 1991. Great Lakes embryo mortality edema, and deformities syndrome (GLEMEDS) in colonial fish-eating birds: Similarity to chick-edema disease. *Journal of Toxicology and Environmental Health*, 33, 455–520.

GOCHFELD, M., 1975. Developmental defects in common terns of Western Long Island, New York. *Auk*, 92, 58–65.

GOCHFELD, M., 1980. Tissue distribution of mercury in normal and abnormal young common terns. *Marine Pollution Bulletin*, 11, 362–377.

GOEDE, A.A. and DE BRUN, M., 1984. The use of bird feather parts as a monitor for metal pollution. *Environmental Pollution, Series B*, 8, 281–298.

HANSSEN, O.J., 1982. Evaluation of some methods for censusing larid populations. *Ornis Scandinavica*, 13, 183–188.

HAYS, H. and RISEBROUGH, R.W., 1972. Pollutant concentration in abnormal young terns from Long Island Sound. *Auk*, 89, 19–35.

HICKEY, J.J. (ed.), 1969. *The Peregrine Falcon Populations: Their Biology and Decline*. Madison, Wisconsin: University of Wisconsin Press, 596p.

HICKEY, J.J. and ANDERSON, D.W., 1968. Chlorinated hydrocarbons and eggshell changes in raptorial and fish-eating birds. *Science*, 162, 271–273.

HUSSELL, D.J.T., 1972. Factors affecting clutch size in Arctic passerines. *Ecological Monographs*, 42, 317–364.

JENKINS, C.D.; NILES, L.J., and WESSEL, J., 1990. Survey of Colonial Nesting Waterbirds on the Atlantic Coast of New Jersey. Trenton, New Jersey: New Jersey Department of Environmental Protection, 15p.

KLOMP, H., 1970. The determination of clutch size in birds: A review. *Ardea*, 58, 1–124.

KUSHLAN, J.A., 1986. Colonies, sites, and surveys: The terminology of colonial waterbird studies. *Colonial Waterbirds*, 9, 119–120.

LACK, D., 1968. *Ecological Adaptations for Breeding in Birds*. London: Methuen, 409p.

MCNICHOLL, M.K., 1975. Larid site tenacity and group adherence in relation to habitat. *Auk*, 92, 89–104.

MONTEVECCHI, W., 1978. Nest site selection and its survival value among laughing gulls. *Behavioral Ecology and Sociobiology*, 4, 148–161.

MOUSSEAU, P., 1984. A comparison of two methods to assess the breeding success of ring-billed gulls. *Journal of Field Ornithology*, 55, 151–159.

MURRAY, B.G., JR., 1985. Evolution of clutch size in tropical species of birds. *Ornithological Monographs*, 36, 505–519.

NISBET, I.C.T., 1973. Courtship-feeding, egg-size and breeding success in common terns. *Nature*, 241, 141–142.

NISBET, I.C.T., 1989. Long-term ecological studies of seabirds. *Colonial Waterbirds*, 12, 143–147.

NISBET, I.C.T. and DRURY, W.H., 1972. Measuring breeding success in common and roseate terns. *Bird Banding*, 41, 97–106.

NISBET, I.C.T.; WINCHELL, J.M., and HEISE, A.E., 1984. Influence of age on the breeding biology of common terns. *Colonial Waterbirds*, 7, 117–126.

NRC (NATIONAL RESEARCH COUNCIL, Marine Board), 1990. *Managing Troubled Waters—The Role of Marine Environmental Monitoring*. Washington, D.C.: National Academy Press, 125p.

O'CONNOR, J.S. and DEWLING, R.T., 1986. Indices of marine degradation: Their utility. *Environment and Management*, 10, 335–343.

OSBORN, P., 1979. Seasonal changes in the fat, protein and metal content of the liver of starling *Sturnus vulgaris*. *Environmental Pollution*, 19, 145–155.

PEAKALL, D.B., 1992. *Animal Biomarkers as Pollution Indicators*. New York: Chapman and Hall, 291p.

PEAKALL, D.B.; CADE, T.C.; WHITE, C.M., and HAUGH, J.R., 1975. Organochlorine residues in Alaskan peregrines. *Pesticide Monitoring Journal*, 8, 255–260.

RATCLIFFE, D.A., 1967. Decreases in eggshell weight of certain birds of prey. *Nature*, 215, 208–210.

RATCLIFFE, D.A., 1972. The peregrine population of Great Britain in 1972. *Bird Study*, 19, 117–156.

RYDER, J.P., 1980. The influence of age on the breeding biology of colonially nesting seabirds. *In:* BURGER, J.; OLLA, B.L., and WINN, H.E. (eds.), *Behavior of Marine Animals, Vol. 4.* New York: Plenum, pp. 153–168.

SAFINA, C. and BURGER, J., 1983. Effects of human disturbance on reproductive success in the black skimmer. *Condor,* 85, 164–171.

SAFINA, C. and BURGER, J., 1988. Ecological dynamics among prey fish, bluefish and foraging common terns in a coastal Atlantic system. *In:* BURGER, J. (ed.), *Seabirds and Other Marine Vertebrates: Competition, Predation and Other Interactions.* New York: Columbia University Press, pp. 95–173.

SOUTHERN, W.E., 1977. Colony selection and colony site tenacity in ring-billed gulls at a stable colony. *Auk,* 94, 469–478.

SOUTHERN, L.K. and SOUTHERN, W.E., 1982. Effect of habitat decimation on a ring-billed gull colony and nest site tenacity. *Auk,* 99, 328–331.

SPENDELOW, J. and PATTON, S.R., 1988. National atlas of coastal waterbird colonies in the contiguous United States: 1976–1982. *Biological Reports,* 88 (5). Washington, D.C.: United States Fish and Wildlife Service, 326p.

STOREY, A.E., 1987a. Characteristics of successful nest sites for marsh-nesting common terns. *Canadian Journal Zoology,* 65, 1411–1416.

STOREY, A.E., 1987b. Adaptations for marsh nesting in common and Forsters' terns. *Canadian Journal Zoology,* 65, 1417–1420.

STOWE, T.J., 1981. Accuracy of measuring trends in seabird numbers. *Seabird Report 1977–1981,* 6, 35–38.

THOMPSON, B.C. and SLACK, R.D., 1984. Post-fledging departure from colonies by juvenile least terns in Texas: Implications for estimating productivity. *Wilson Bulletin,* 96, 309–313.

ZAR, J.H., 1984. *Biostatistical Analysis.* Englewood Cliffs, New Jersey: Prentice-Hall, 620p.