The Effects of Gull Predation on the Colony Reproductive Success of Terns and Skimmers in Virginia

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of

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DEDICATION

This work is dedicated to my parents and siblings. They have given a lifetime of support and encouragement to this wide-eyed nature boy, and I am eternally grateful.

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ABSTRACT

During the months of June through August in 1990 and 1991, seven colonies of beach-nesting Common Terns (Sterna hirundo), Least Terns (S. antillarum), Gull-billed Terns (S. nilotica) and Black Skimmers (Rynchops niger) were studied on five barrier islands off the coast of Virginia's Eastern Shore. The objectives of this study are to 1) determine factors that limit reproductive success of terns and skimmers, 2) determine the percentage of egg and chick losses to predatory Herring (Larus argentatus), Great Black-backed (L. marinus), and Laughing Gulls (L. atricilla), 3) compare identified levels of gull predation for tern/skimmer colonies on islands that contain nesting gulls with colonies on islands that lack nesting gulls, and 4) develop improved methodology for estimating levels of gull predation in tern/skimmer colonies. Data were collected through a combination of nest monitoring activities, visual observations, and a quantitative index of gull activity based on counts of gull footprints within colony boundaries.

Fledging success of terns and skimmers in the study area was low at 3% of all eggs produced (n = 1194 total eggs). Three out of the four study species were determined to be reproducing at a rate below that which would maintain a stable population size.

Four factors were identified that detrimentally impacted reproductive success: confirmed gull predation, nest flooding due to unusually high tides (washout), exposure to extremes of temperature, and an "other" category (those instances in which the agent of mortality could not be determined). Confirmed gull predation accounted for 29% of all eggs produced, and was the single most important factor in egg and young mortality of the three that could be identified. Washouts and exposure claimed 23% and 2% respectively of all eggs produced. The majority of eggs and young (43%) were lost to undetermined factors.

Tern/skimmer colonies located on islands that also contained nesting gulls experienced significantly higher losses of eggs and young to predatory gulls than tern/skimmer colonies located on islands that did not contain nesting gulls. These data are reinforced by new methodologies developed in this study for the estimation of gull predation levels in a colony .

Predation by Herring and Great Black-backed Gulls threatens the long term population stability of terns and skimmers on the Virginia barrier islands. However, colony washouts also play a major role in determining reproductive success in a given breeding season. Perhaps a greater threat to terns and skimmers, and a suggested topic for further study in the region, is the apparent nest site competition with gulls which may force terns and skimmers to nest in habitats that are prone to frequent washouts.

The Effects of Gull Predation on the Colony Reproductive Success of Terns and Skimmers in Virginia

INTRODUCTION

Beach-nesting terns (Sterna) and skimmers (Rynchops) face many threats that can limit their reproductive success in any given nesting season. These threats prevent eggs and young from maturing to fledging age and therefore decrease subsequent recruitment into the breeding population. Nesting threats that colonial beach-nesters face can be categorized as weather-related factors, human disturbances, and predation. Weather-related factors include nest flooding due to high tides (Palmer 1941, Kress et al. 1983, Erwin and Smith 1985, McKearnan and Cuthbert 1989, Beck et al. 1990, Burger and Gochfeld 1990) and exposure of eggs and young to extremes of temperature (Palmer 1941, Marks 1986, Burger and Gochfeld 1990). Human disturbances can be classified as direct, such as market hunting and egg collecting (Bailey 1913, Bent 1921, Jackson and Jackson 1985), or indirect, such as disturbance from human recreational activities (Burger and Gochfeld 1990) or loss of appropriate nesting habitat due to coastal development (Erwin et al. 1981, Smith 1982, Beck et al. 1990, Burger and Gochfeld 1990, Keller 1992). Predation refers to the take of viable eggs and young by avian or mammalian predators (Kadlec and Drury 1968, Hatch 1970, Langham 1972, Burger and Lesser 1978, Randall and Randall 1981, Kress et al. 1983, Kirkham and Nettleship 1987, Hulsman and Smith 1988, Langham and Hulsman 1986, McKearnan and Cuthbert 1989).

The import that any one of these threats may have on the breeding success of terns and skimmers varies both within and between nesting seasons, and over longer periods of time. For example, colony losses to flooding or exposure are primarily functions of weather-related phenomena, and their severity and frequency vary accordingly. In contrast, colony losses to market gunning and egging, which were extreme during the late 1800s and early 1900s (Bailey 1913, Bent 1921), are practically non-existent in the United States today due to the passage of legislation that made these practices illegal.

Predation is a factor that has contributed to nest losses in colonies of beach-nesting birds over evolutionary time. This fact is evidenced by the anti-predator mechanisms and behaviors exhibited by many beach-nesting species. Crypsis, nest defense, distraction displays, creche behavior, nesting synchrony, the propensity for more "docile" species to associate with more "aggressive" species, and colonial nesting itself are aspects of tern and skimmer breeding biology that have largely been shaped by predatory pressure (Lemmetyninen 1971, Fuchs 1977, Erwin 1979, Hulsman and Langham 1985, Hulsman and Smith 1988). Both mammalian and avian predation caused by foxes, weasels, crows, owls, falcons, harriers, night-herons, jaegers, turnstones, gulls and others have contributed to the evolution of tern and skimmer nesting behaviors (Palmer 1941, Lemmetyinen 1971, Minsky 1980, Helle et al. 1988, Kaiser et al. 1988, Burger and Gochfeld 1990).

Although the breeding biology of terns and skimmers has evolved under consistent predatory pressure, the species exerting that pressure or the relative levels of predatory pressure in different regions may not be evolutionary constants. For example, localized beach-nester populations have been severely impacted by predaceous rats (Rattus norvegicus) and feral house cats (Felis catus) (Blus and Stafford 1980, Shields and Townsend 1985, Burger and Gochfeld 1990, Keller 1992). Terns and skimmers breeding on the Atlantic Coast of North America did not experience predation from cats and rats until the European settlement of North America. Likewise, population increases in native, historical predators can lead to an increase in predatory pressure from these species. For example, Hatch (1970) reported that increases in Herring Gull (Larus argentatus) populations in Maine caused increased levels of predation by this species on Common Terns (Sterna hirundo). While the breeding biology of terns and skimmers has evolved general antipredator mechanisms, local populations of terns and skimmers may not be able to withstand rapid changes in predator species or levels of predation encountered.

Corresponding to rapid increases in population numbers of Herring and Great Black-backed Gulls (L. marinus), many researchers have cited gull predation on eggs and young as a major factor contributing to decreases in the reproductive colony success of nesting terns and skimmers (Drury 1965, Kadlec and Drury 1968, Andersson 1970, Hatch 1970, Blus and Stafford 1980, Randall and Randall 1981, Courtney and Blokpoel 1983, Kress et al. 1983, Kirkham and Nettleship 1987, Helle et al. 1988, McKearnan and Cuthbert 1989, Williams et al.1990, Burness and Morris 1992). Herring and Great Black-backed Gulls, as well as other gull species, are implicated as important predators on nesting terns in Europe (Lemmetyninen 1971, Helle et al. 1988), South Africa (Randall and Randall 1981), and the Australian region (Hulsman 1977, Langham and Hulsman 1986). Hulsman and Smith (1988) found that gull predation was one of the "major causes of nesting failure" in a colony of Black-naped Terns (S. sumatrana) in Australia. Another Australian study noted that gulls were "responsible for the total annihilation of several small subcolonies" of nesting Crested Terns (S. bergii), adding that one colony lost "90 percent of its eggs" to gulls (Langham and Hulsman 1986).

Along the Atlantic Coast of North America, the expansion in population numbers and breeding range of Herring and Great Black-backed Gulls, and the resultant predation on colonies of terns and skimmers, has been well documented. Kirkham and Nettleship (1987) identified gulls as a threat to a declining population of Roseate Terns (S. dougallii) in Nova Scotia. Kress (1983) stated that the "spectacular increase in gull numbers" helped to bring about a 40 year population decline in Common and Arctic Terns in Maine. In New Jersey, Burger and Lesser (1978) maintained that rapid population increases of Herring Gulls in Ocean County "significantly increased the rate of nest predation" on Common Terns. Burger and Shisler (1978) reported that Herring Gull numbers on Clam Island, New Jersey had doubled each year since 1964. Burger and Gochfeld (1990) found over the course of a 13 year study that gull predation accounted for between 20-40% of Black Skimmer mortality in New Jersey.

Neither Herring nor Great Black-backed Gulls bred historically on the Delmarva Peninsula (Bailey 1913). Herring Gulls were first reported as breeders in the 1960s, and their numbers doubled in this region between 1976 and 1977 (Erwin et al. 1981). Williams et al. (1990) documented stable to slightly increasing numbers of Herring Gulls over the course of a 14-year study of Virginia's barrier island avifauna. Williams et al. (1990) also noted a "dramatic increase" in the breeding population of Great Black-backed Gulls, which did not nest in Virginia prior to 1976. Subsequent research on Virginia's barrier islands documented gull predation on Common Terns and Black Skimmers (Smith 1982) and on Royal Terns (Sterna maxima) (Ihle 1984). Since Herring and Great Black-backed Gulls have not historically bred in Virginia, they constitute a predatory threat to Virginia's terns and skimmers that has only recently developed. Herring and Great Black-backed Gulls are now present in large numbers and often in close proximity to colonies of Black Skimmers (Rynchops niger), Common Terns, Least Terns (S. antillarum), and Gull-billed Terns (S. nilotica) on the Virginia barrier islands.

While this evidence suggests that gull predation has become a serious impediment to the reproductive colony success of terns and skimmers, the extent of gull disturbance reported varies widely. Some colonies may be disrupted to the point of total reproductive failure, while others are subjected to only minimal gull disturbance (Burger and Lesser 1978). In many studies, gulls are not cited as a significant threat to tern or skimmer reproductive success (Langham 1972, Morris et al. 1976, Erwin 1979, Hulsman and Langham 1985, Jackson and Jackson 1985).

Part of the variation in the gull predation induced on different tern and skimmer colonies may be due to the proximity of these colonies to gull colonies. Burger and Lesser (1978) found that only tern colonies on islands that also supported gull colonies incurred losses to gull predation. Likewise Southern and Southern (1984) documented higher predation by Herring Gulls on Ring-billed Gull (L. delawarensis) colonies that were adjacent to Herring Gull colonies as opposed to those further from nesting Herring Gulls.

The size of a tern colony may also contribute to the frequency and intensity of gull predation that a colony incurs. Burger (1984) found that Least Tern colonies with over 80 individuals suffered higher losses to predation than Least Tern colonies with fewer than 80 individuals.

Variation in the amount of reported gull predation may also arise because it can be difficult to accurately determine the level of gull predation a tern/skimmer colony incurs, even in the absence of a colony size or location effect that can influence predation. Unless a colony can be observed continuously throughout an entire season, it is impossible to quantify with full confidence the exact number of eggs and chicks lost to predators. Thus, the extent of gull predation reported must be estimated based on visual observations and evidence of predation left at the colony site following a predatory event. The difficulty in achieving accurate measurements may be the reason there have been few studies that specifically focus on the impacts of predaceous gulls on colonial beach-nesters. Those that address predation are often based solely on descriptive observational information (Hatch 1970, Hulsman 1977, Burger and Lesser 1978, Burger and Gochfeld 1990), inferences drawn from eggshell fragments at tern nests (Burger and Lesser 1978, Nol and Brooks 1982), or some combination of these methods.

The limitations in these methods are that they are inconclusive. It is impractical to record visual observations continuously throughout the nesting season, and nest monitoring by itself does not yield accurate information on gull predation since gulls may not always leave behind evidence of their activity. Consequently, gull activity estimates based solely on visual observations and nest checks for evidence of predation probably under-represent the true level of gull predation in any given colony.

Conversely, some researchers have considered any tern and skimmer eggs or young that apparently disappear from their colonies to have been taken by predators (Nisbet 1975, Morris and Hunter 1976, Hulsman 1977, Houde 1983, Quinn and Morris 1986). A problem with this assumption is that it may over-represent the level of predation if other factors are involved in the disappearance of eggs and young. These factors include the possibilities that eggs and chicks perish from causes other than predation and are scavenged from the colony; eggs roll away from their nests or chicks leave the colony and thus are not counted during nest monitoring; or that chicks concealed in vegetation within the colony escape detection during nest monitoring due to their crypsis. These factors may or may not operate in a given colony or under specific study regimes. For example, a colony site with sparse vegetative cover is less likely to harbor concealed chicks than a densely vegetated site. Also, frequent visitation to a colony by the researcher can reveal the cause of egg or chick mortality before remains are scavenged from the colony.

The role that predatory gulls play in the reproductive success of terns and skimmers is at issue in Virginia. Large numbers of Herring Gulls have only been present in the Commonwealth during the nesting season for approximately 30 years, and Great Black-backed Gulls for approximately 15 years. The impact that these avian predators have on the reproductive success of nesting terns and skimmers in Virginia has increased from near zero to its present level in a short period of time. Currently, gull populations in Virginia are still increasing, beach-nester populations may be declining, and gull predation has not been studied as it relates to tern and skimmer reproductive success (Beck et al. 1990, Williams et al. 1990). Thus, the implications that gull predation may have on management strategies for terns and skimmers in Virginia have not been investigated.

OBJECTIVES

In an effort to determine the effects of gull predation on the colony reproductive success of Virginia's terns and skimmers, single and mixed-species colonies of Common Terns, Least Terns, Gull-billed Terns, and Black Skimmers were studied on Virginia's barrier islands in 1990 and 1991. The specific objectives of this study are to:

1) identify causes for nest failures in colonial beach-nesters
2) determine the confirmed proportion of nest failures attributable to gulls
3) assess any differential risk to beach-nester colonies on islands that contain nesting gulls compared to beach-nester colonies on islands that lack nesting gulls
4) improve methodology for determining levels of gull predation

STUDY AREA

STUDY COLONIES: During 1990 and 1991, seven single and mixed-species colonies of terns and skimmers were monitored on five barrier islands along the coast of Virginia's Eastern Shore in Northampton and Accomack counties. Study colonies were located on Cobb and Hog Islands in 1990, and on Dawson Shoals, Cedar "Extension" (an accreted sandbar between Cedar Island and Metompkin Island), and Metompkin Islands in 1991 (see Figure 1. 1990 colony site locations are illustrated in Figure 2 and 1991 colony sites in Figure 3). With the exception of Hog Island, which contains a biological field station and one seasonal private dwelling, all barrier islands in this study are uninhabited by humans. All five islands are established as preserves of the barrier island ecosystem and are managed by the United States Fish and Wildlife Service, the Virginia Department of Game and Inland Fisheries, or The Nature Conservancy's Virginia Coast Reserve. The islands that comprise the Virginia Coast Reserve and those under the jurisdiction of state and federal conservation agencies form a chain of barrier island beach that is the longest continuous stretch of undeveloped coastline along the Atlantic Coast of the United States.

All seven colony sites were located in overwash fans on substrates that varied from loose sand to hard-packed sand and shell. The amount of vegetation at each site also varied between near zero to approximately 40% vegetated cover. Dominant plant species at vegetated colony sites were Beach Grass (Ammophila breviligulata), Sea Rocket (Cakile edentula) and Seaside Goldenrod (Solidago sempervirens) (McCaffrey and Dueser 1990). There was no evidence that mammalian predators were present at any of the colony sites in 1990 or 1991. Potential mammalian predators in the study area include Red Fox (Vulpes vulpes), Raccoon (Procyon lotor), and Mink (Mustela vison)

(Dueser et al. 1979).

The variation in colony site characteristics is due in part to differences in habitat preference of the species that made up study colonies. Species composition varied from small monospecific Least Tern colonies, to subsets of larger mixed-species colonies that included Common Terns, Gull-billed Terns, Royal Terns (S. maxima), Caspian Terns (S. caspia), and Black Skimmers. Species composition, locations, and general habitat information for the seven study colonies are outlined in Tables 1 and 2 and described in greater detail below:

STUDY COLONY SELECTION: The selection of tern and skimmer colonies included in this study was based on several factors. In order to minimize differences that colony site habitat parameters may have on predation, only barrier island beach colonies were studied. Selected colonies were as ecologically similar as possible so that legitimate intercolony comparisons of reproductive success could be produced. Selected colonies were free of mammalian predation so that the identification of nest predators was simplified. Efforts were made to study approximately equal numbers of terns and skimmers nesting on islands that also contained nesting gulls, and on islands that lacked nesting gulls. Study colonies were large enough to obtain meaningful samples of data collected, yet not so large that colony monitoring could not be accomplished by a single researcher in less than twenty minutes time (mean = 56 nests per colony). Subcolonies of larger colonies selected for study were spaced in such a way that monitoring activities were not disruptive to the entire colony.

COLONY DESCRIPTIONS: Colony A. Colony A was located in an overwash fan between the wrack line and the primary dune on the south end of Hog Island in 1990 (Figure 2). The colony site occurred on a sandy substrate with approximately 20% vegetative cover. No gulls nested on Hog Island in 1990. This colony contained 24 Least Terns, 54 Common Terns, and 136 Black Skimmers. Twelve Least Tern and 27 Common

Tern nests were studied.

Colony B. Colony B was located in an overwash fan near the middle of Hog Island in 1990 (Figure 2). The substrate at the site was sandy with approximately 20% vegetative cover. No gulls nested on Hog Island in 1990. This colony contained 27 Least Terns, 34 Common Terns, and 124 Black Skimmers. Nine Least Tern and 16 Common Tern nests were studied.

Colony C. This colony was a monospecific Least Tern colony studied on Cobb Island in 1990 (Figure 2). Colony C occurred in a broad overwash fan near the south end of Cobb Island. The colony site substrate was a loose sand with approximately 5% shell cover. Live vegetation covered approximately 20% of the colony site. Colony C was located within approximately 50 meters of a small nesting colony of 36 Herring Gulls and five Great Black-backed Gulls. Total numbers of more than 500 Herring Gulls and over 50 Great Black-backed Gulls nested on Cobb Island in 1990. Up to forty adult Least Terns were observed at colony C and 11 nests were tracked in this study.

Colony D. Colony D was located at the southern end of north Metompkin Island in 1991 (Figure 3). The colony site occupied an overwash fan between the wrack line and a broad Spartina marsh. The substrate contained hard-packed sand over a relict shellbank such that the colony site exhibited approximately 30% shell cover. Vegetation amounted to approximately 40% cover. No gulls are known to have nested on north Metompkin in 1991. Forty two Common Tern nests (84 adults), 34 Gull-billed Tern nests (68 adults), and 36 Black Skimmer nests (72 adults) were studied at colony D.

Colony E. Colonies E and F occurred at the northern and southern ends, respectively, of a sandbar island between south Metompkin and north Cedar Island in 1991 (Figure 3). The sandbar island, known as "Cedar Extension", contained an area of low dunes and grassy tumps on the northern and southern ends. The northern dune area supported a gull colony with 336 Herring and 17 Great Black-backed Gulls. Nest density thinned at its southern edge as the northern dunes gave way to a low overwash area. Individual gull nests were scattered through this area on small grassy windrows and extended down into the southern dune area. Thus, there was no spot on the island greater than approximately 50 meters to the nearest gull nest, but the only aggregation of gulls dense enough to be termed a "colony" was located on the north end of this island.

Colony E was located at the northern edge of the Cedar Extension gull colony in 1991 (Figure 3). Eighty six Common Terns (43 nests) and eight Black Skimmers (four nests) colonized an area on the low dunes and grassy windrows that already supported nesting gulls. Individual nests in this colony were located within two meters of active Herring Gull nests. The colony site was slightly elevated above the overwash areas on this island and exhibited a loose sandy substrate with approximately 40% vegetative cover.

Colony F. Colony F was a subset of a large mixed tern and skimmer colony located at that colony's northern edge (Figure 3). The majority of the birds in this colony occupied the southern dune area on Cedar Extension. This colony contained approximately 500 Common Terns, 200 Gull-billed Terns, 80 Royal Terns, two Caspian Terns, and 750 Black Skimmers. Fifty nine Common Tern, 30 Gull-billed Tern, and 27 Black Skimmer nests were monitored as "colony F". These nests were located in a low overwash area north of the southern dunes on a sandy substrate with approximately ten percent vegetative cover. As previously described, nests in colony F occurred within 50 meters of individual gull nests, but were approximately 150 meters south of the gull colony on the north end of the island.

Colony G. This colony occurred in a wide overwash on Dawson Shoals in 1991 (Figure 3). Dawson Shoals is a low sandbar island that is almost completely devoid of living vegetation. The colony site substrate was a loose sand. No gulls nested on Dawson Shoals in 1991. Seventy six Common Terns and 224 Black Skimmers comprised this colony. Thirty eight tern and 113 skimmer nests were studied.

The objectives of this study are met by comparing reproductive success of tern/skimmer colonies that are exposed to predatory pressure from gulls to tern/skimmer colonies that are free from gull predation. Since an appropriate "gull free" condition could be neither found nor artificially created, it had to be approximated. Reproductive colony success of tern/skimmer colonies on islands that also contained nesting gulls ("gull present colonies") was compared to that of colonies on islands that lacked nesting gulls ("gull absent colonies") (see Burger and Lesser, 1978). It should be noted that Herring and Great Black-backed Gulls are nearly ubiquitous on the Virginia barrier islands so truly "gull absent" tern and skimmer colonies do not exist. However, the greatest numbers of gulls are concentrated in the vicinity of gull nesting colonies, and gulls are more consistently present at "gull present" colonies than at "gull absent" colonies. Locations of colonies considered gull absent and gull present colonies are indicated in Table 2.

METHODS

METHODS: Reproductive colony success of terns and skimmers, factors that limited reproductive success, and the impact of predatory gulls were determined through a combination of nest monitoring, visual observations, and a quantitative index of gull activity within tern and skimmer colonies.

Nest Monitoring. All nests included in monitoring activities were marked with natural color, 40 cm, wooden paint stirrer sticks at a distance of approximately one meter from the nest. Marked nests were checked once to twice per week in 1990, and at least twice per week in 1991. Eggs and young were monitored from incubation to fledging. Young were considered fledged when they became capable of flight.

During each visit, the number and condition of eggs and young was recorded in addition to any evidence of confirmed predation (broken eggshells and "missing" eggs or young with gull footprints near the nest). Other causes of egg or young mortality such as exposure or nest washout were also determined through regular nest checks. Mortality due to exposure was evidenced by abandoned eggs or dead chicks that appeared heat-stressed but not outwardly injured. Nest losses to washout were determined by water marks and smoothed sand around nests, inspection of recent high tide lines, and the correspondence of these findings with the occurrence of unusually high tides and/or strong storms. Eggs and young that were reported missing but left no evidence at the nest of the agent of their disappearance were assigned to an "other" category.

Visual Observations. Colonies were observed in 1990 and 1991 to assess qualitatively the behavior of nesting terns and skimmers toward the predatory advances of gulls. The total observation time was 145 hours (53 hrs. in 1990 and 92 hrs. in

1991) which was collected in 115 colony visits. In 1991, a portion of the gull activity observed (20.17 hrs.) was quantified by recording the amount of time in a ten minute period that gulls caused terns or skimmers to actively engage in nest defense behaviors. These behaviors were lumped as any that caused nesting terns and skimmers to be away from their nests and includes upflights, aerial scolding above the colony, and aerial bombardment. The percentage of time during these observations that gull disturbance occurred was compared between gull present and gull absent colonies.

Observations were recorded at a distance from the colonies greater than that which would cause any single individual in the colony to flush (usually approximately 100 meters). Observations recorded during high tide often had to be taken within 100 meters due to the colonies' close proximity to the high tide line. At these times, observations were recorded from beneath a sand colored sheet at no less than 30 meters from the colony. The crypsis afforded by the sheet and seated or prone posture during observations allowed approach closer than 100 meters without noticeably altering colony behavior.

Gull Activity Index. In 1991, gull activity in tern and skimmer colonies was quantified through counts of gull footprints (the impression of a single gull foot) in the colonies. The method of this sampling was based on a modified line-intercept method described by Rimmer and Deblinger (1990) for determining predator activity in the vicinity of Piping Plover (Charadrius melodus) nests. The method was further modified for this study to make it appropriate for colonial beach-nesting birds. Prints were counted weekly along a perpendicular axis of four lines extending 8 meters from randomly selected nests. The eight meter distances from each nest were paced off each visit so that measuring devices were unnecessary within the colonies. All gull prints that intersected the four lines were counted and summed to arrive at a total number of prints recorded in the vicinity of each selected nest. The total number of prints counted during the nesting season divided by the number of weeks individual colonies were sampled produced an average number of prints per week. This number constituted an indirect but quantifiable measure of gull activity within tern and skimmer colonies that could not be determined through visual observation. (See Figure 4 for a hypothetical example of how the gull activity index would be derived for a single nest.) In the Rimmer and Deblinger (1990) study, the predator index for each plover nest was measured once annually and the sample lines extended 50 meters from each nest. (Gysel and Lyon 1980, Minsky 1980, Rimmer and Deblinger 1990,).

Variation in the total number of nests sampled per colony was due to differences in colony size and persistence. The number of nests sampled in a given colony was dependent on the approximate area that each colony encompassed. The optimum number of nests sampled is that which gives the most total coverage of all the nests in the colony, but minimizes overlap between nests. The number of nests sampled is equal to the number of 8 meter sampling grids that would span the colony's total length and width. A hypothetical example of the number of nests sampled given the total number of nests in a colony is illustrated in Figure 5.

Numbered nests were randomly selected for sampling on a weekly basis. The week-long delay between samples was sufficient to allow existing prints to be covered or smoothed by the action of wind or rain. Since certain colonies persisted for a longer period of time than other colonies, the number of weeks that samples were taken varied between colonies.

MINIMIZATION OF RESEARCHER IMPACT: Efforts were taken to minimize researcher disturbance on nesting birds at all times. Activity that mandated researcher presence within colony boundaries (in-colony work) was limited to nest marking, nest monitoring, and sampling selected nests for gull activity. During weather that was least likely to impose heat or cold stress on uncovered eggs and young (warm, dry, cloudy periods), in-colony activity took place for as long as 15 minutes at a time. If more than

15 minutes were required to perform the necessary work, a one-hour waiting period was observed before entering the colony again for another 15 minutes. At no time were more than two 15 minute periods spent in the same colony on any given day. During less than optimal weather conditions, colony visitation was limited to no more than two trips of five or ten minutes per day separated by one full hour out of the colony. During times of extremely hot, cool, or windy weather, or during any amount of rain, no in-colony activities were performed. The majority of in-colony work took place in five to ten minutes, no more than three times per week.

At no time were manipulations of colonies or nests included in this study. Eggs or young were not collected, moved, or handled. Neither adults nor young were captured or banded. Other than the paint sticks used to mark nests, no structures were brought into colonies.

ANALYSIS: Results of nest monitoring, observations, and gull activity indices were compared between gull absent and gull present colonies and subjected to chi-squared analysis to determine independence. Numbers of eggs and chicks in a given colony lost to various agents are expressed as a percentage of the total number of eggs produced in that colony and rounded to the nearest whole number.

Reproductive success (colony fledging success) is presented as both the number of individuals fledged per nest (rounded to the nearest hundredth) and the percentage of all eggs in a colony that produced fledged young. Using data on the number of individuals fledged per nest, it is possible to analyze observed reproductive success in terms of population stability. Assuming that observed fledging success remains constant, two adults per nest divided by the number of young fledged per nest gives the approximate number of breeding seasons it will take for a breeding pair to replace themselves in the population. When the number of breeding seasons arrived at from this formula is compared to the average reproductive lifespan of the species in question, it can be determined if the colony is reproducing at a level that is at, above, or below recruitment. While this method of analysis oversimplifies natural conditions, such as variation in rates of adult and juvenile mortality over time, it provides a simple, rough indication that a colony's number is stable, increasing, or decreasing (Perrins and Birkhead 1983).

For example, the average reproductive lifespan for a Common Tern has been estimated at 12 years (Burger and Gochfeld 1991). If the number of young fledged per pair in a Common Tern colony is 0.5, then each breeding pair of terns in this colony should replace themselves in approximately four years. Thus, over their reproductive lifespan, each breeding pair in this colony should raise six individuals to fledging, four more than necessary to replace themselves in the population. This level of reproductive success is above recruitment.

Reproductive success of all species in this study was subjected to this analysis based on an estimated 12 year reproductive lifespan for terns and a 15 year reproductive lifespan for Black Skimmers (Burger and Gochfeld 1990).

Figure 1: Virginia Eastern Shore and barrier islands.

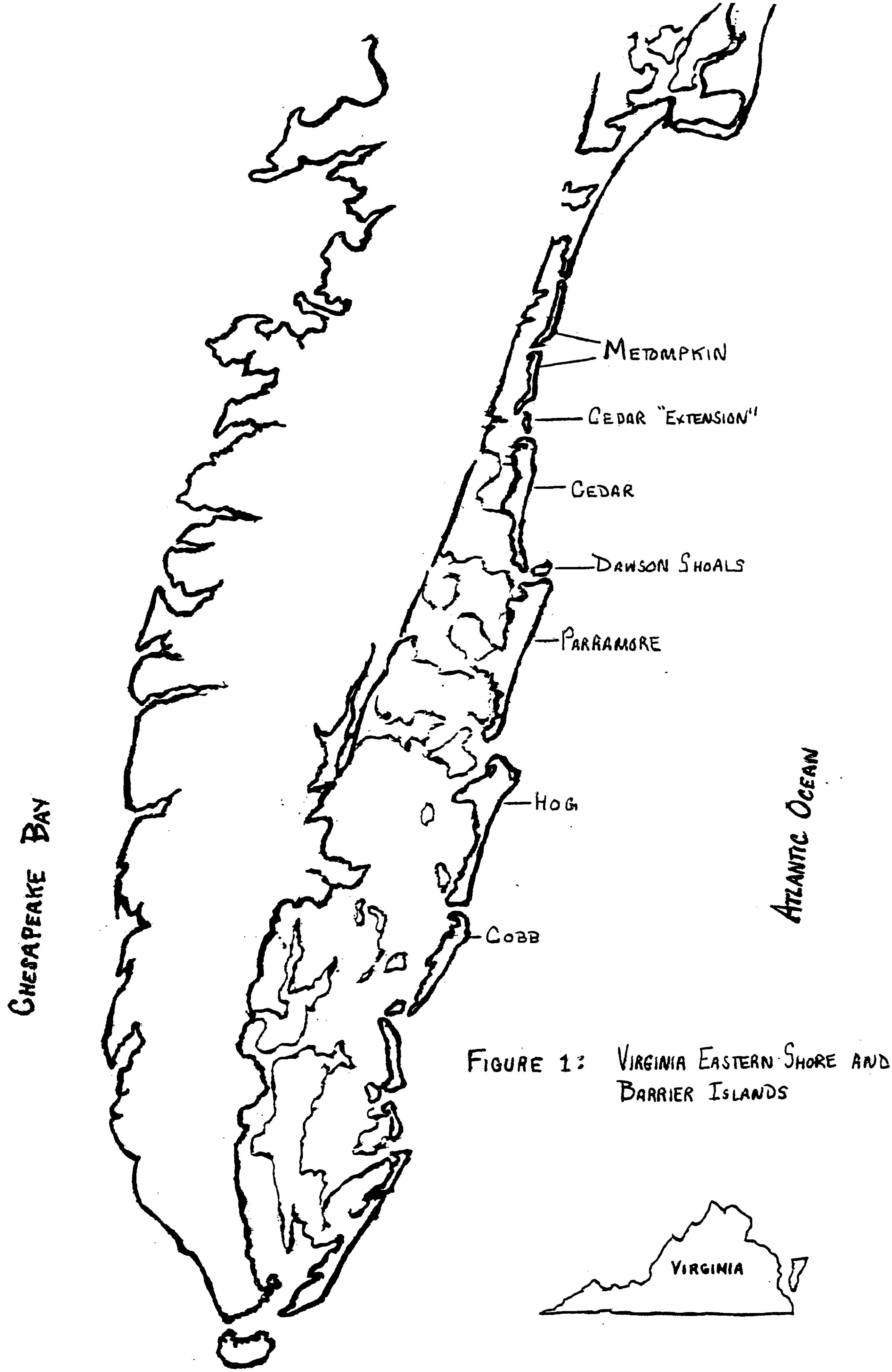

Figure 1: Virginia Eastern Shore and Barrier Islands

Figure 2: 1990 colony sites.

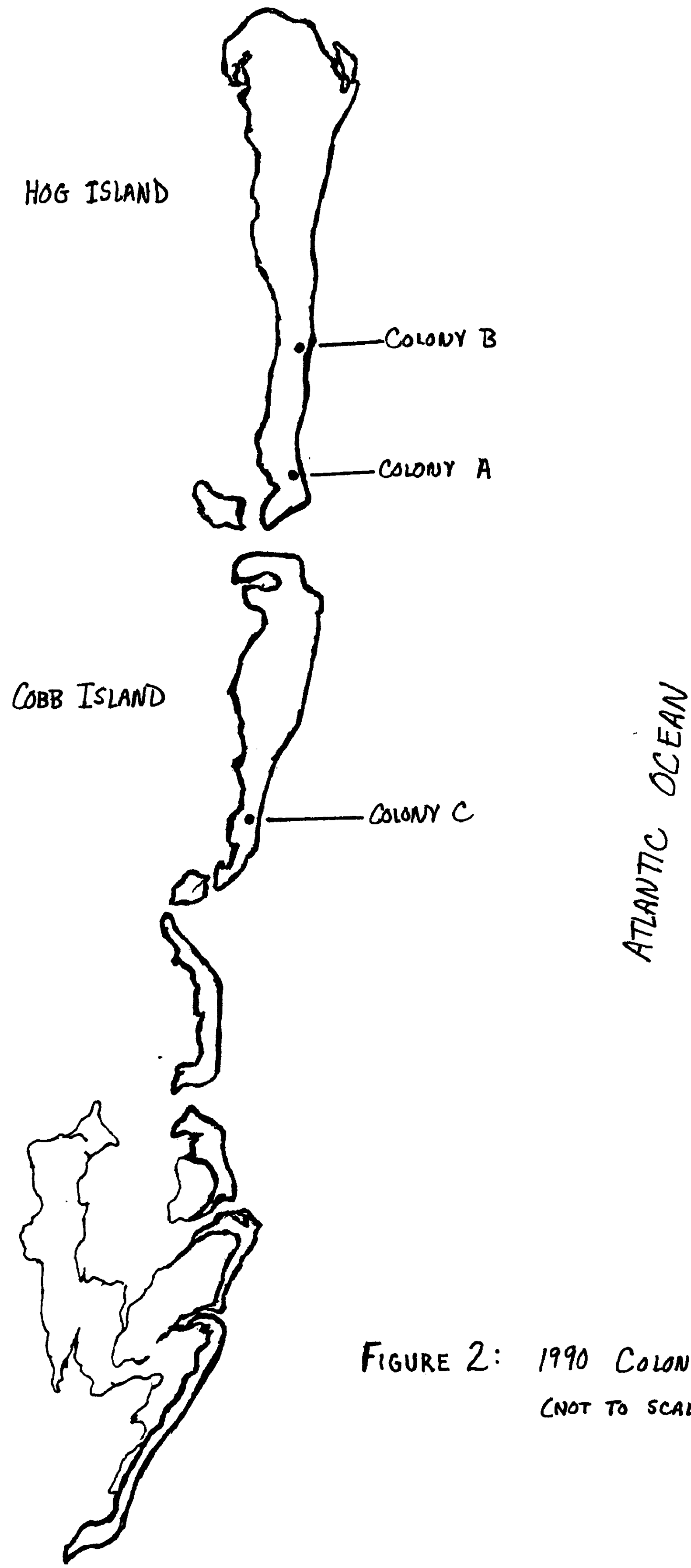

FIGURE 2: 1990 COLONY SITES
(NOT TO SCALE)

Figure 3: 1991 colony sites.

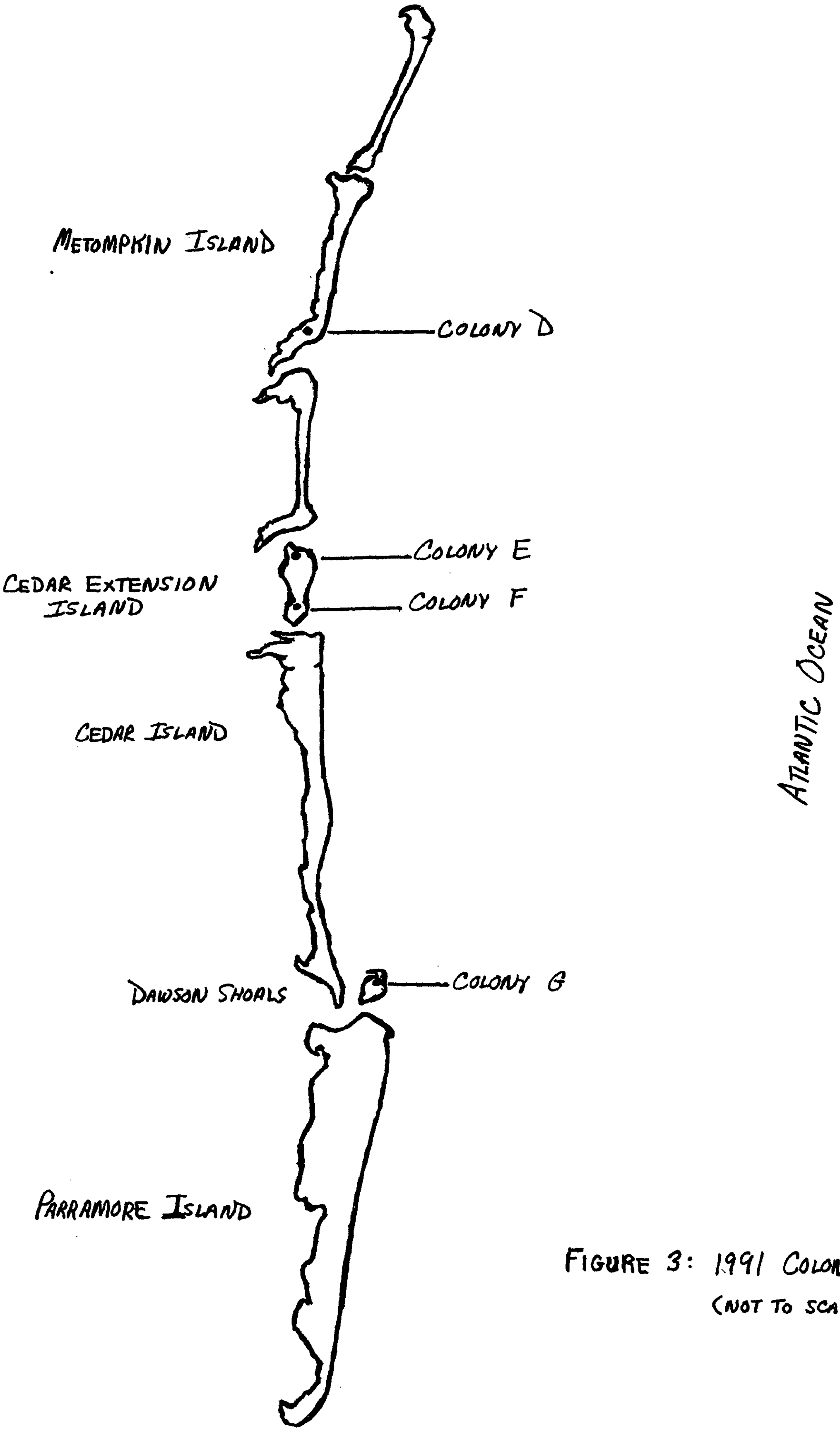

Figure 3: 1991 Colony Sites
(not to scale)

Table 1: Species composition and nest information for all colonies in 1990 and 1991.

Table 1: Species composition and nest information for all colonies in 1990 and 1991.

colony/year studied	species composition	# nests marked	max. # adults
A/1990-south Hog	Least Tern	12	24
	Common Tern	27	54
	Black Skimmer	N/A	136
B/1990-mid-Hog	Least Tern	9	27
	Common Tern	16	34
	Black Skimmer	N/A	124
C/1990-south Cobb	Least Tern	11	40
D/1991-Metompkin	Common Tern	42	84
	Gull-billed Tern	34	68
	Black Skimmer	36	72
E/1991-Cedar Ext. north	Common Tern	43	86
	Black Skimmer	4	8
F/1991-Cedar Ext. south	Common Tern	59	500
	Gull-billed Tern	30	200
	Black Skimmer	27	750
	Royal Tern	N/A	80
	Caspian Tern	N/A	2
G/1991-Dawson Shoals	Common Tern	38	76
	Black Skimmer	113	224

Table 2: Colony site descriptions and gull proximity.

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colony	location	season	gull proximity	substrate	% veg. cover
A	south Hog	1990	gull absent	sand	20%
B	mid-Hog	1990	gull absent	sand	20%
G	Dawson Shoals	1991	gull absent	sand	0%
D	Metompkin	1991	gull absent	sand & shell	40%
C	south Cobb	1990	gull present	sand & shell	25%
F	Cedar Ext. south	1991	gull present	sand	10%
E	Cedar Ext. north	1991	gull present	sand	40%

Figure 4: Gull activity index.

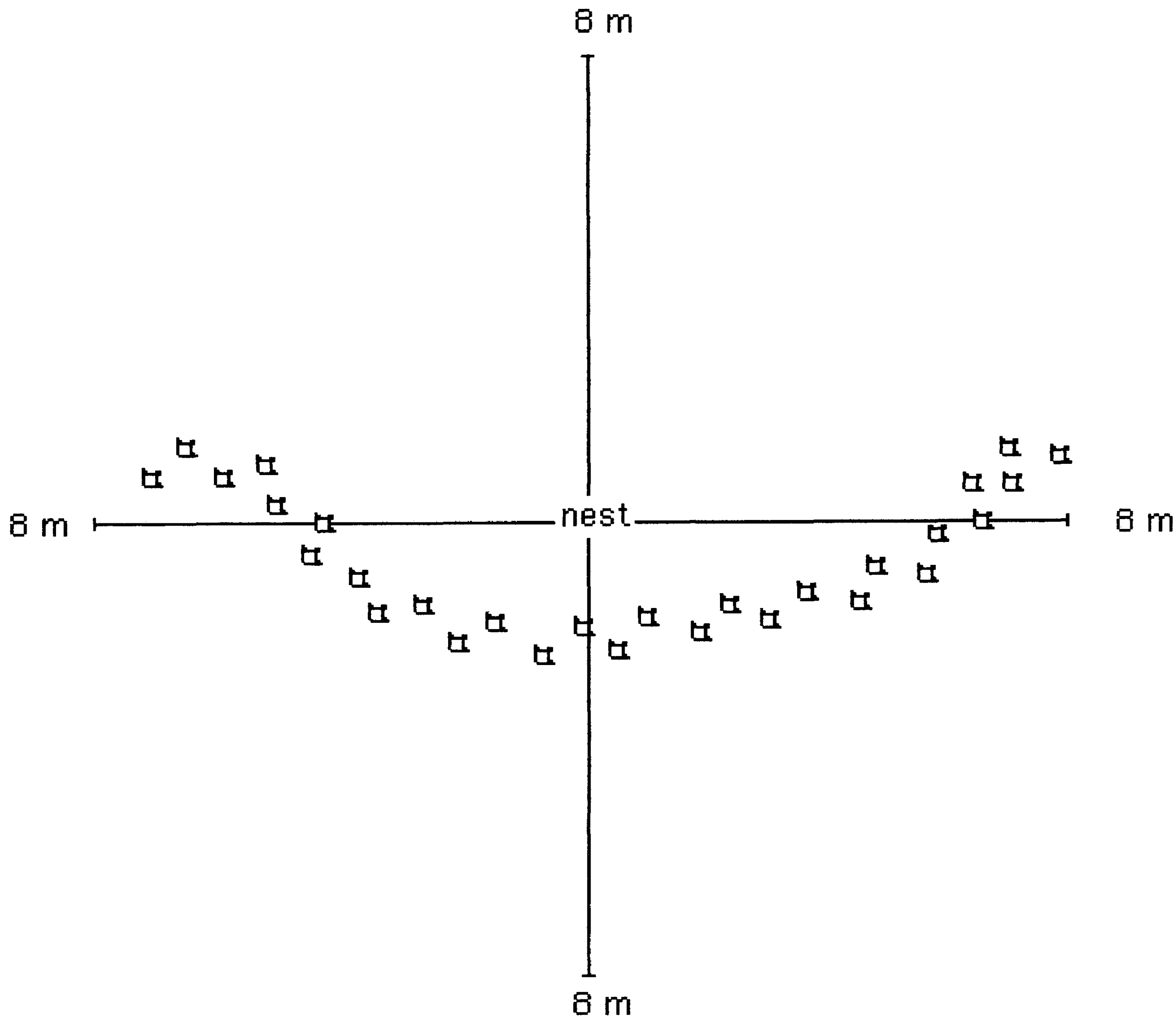

Figure 4. Gull activity index. Three prints cross the transect lines. (not to scale)

Figure 5: Gull activity index nest selection.

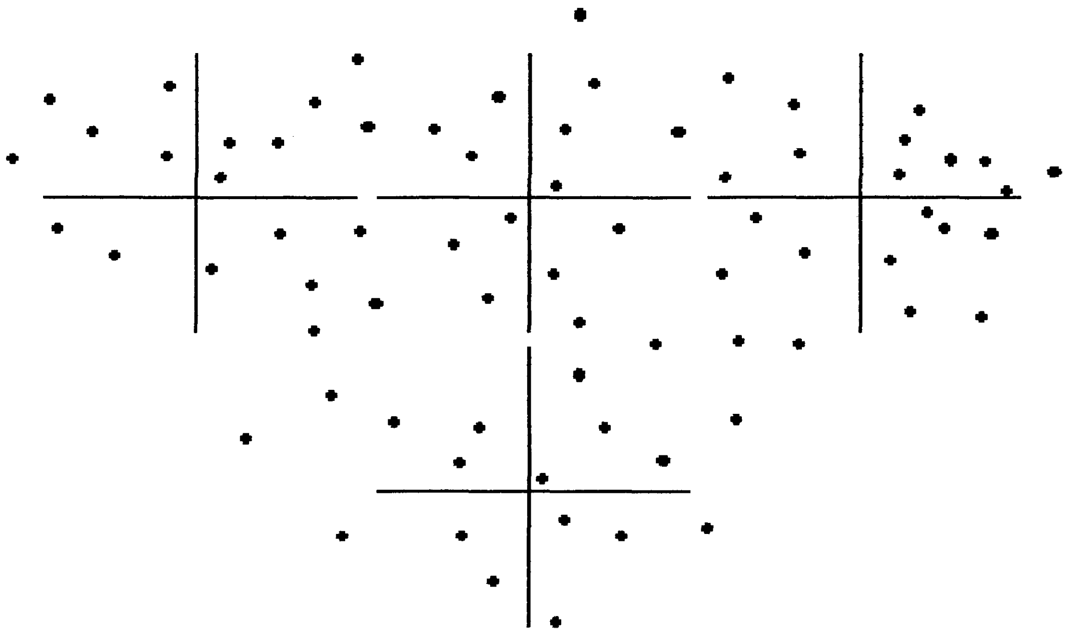

Figure 5. Gull activity index nest selection. Dots represent individual nests. The number of 8 meter grids that span this hypothetical colony at its longest and widest points is four. Thus, four nests would be randomly selected in this colony as sample gull activity index nests. Due to random nest selection, actual distribution of samples may not be regular.

RESULTS

NEST MONITORING : Reproductive Success. Colony reproductive success (defined in this study as fledging success) of terns and skimmers varied from a low of 0 individuals per nest (0% of total eggs produced) to as high as .45/nest or (25%) (Table 3). Average reproductive success for all colonies in 1990 and 1991 was low at .08/nest (3%). Of the tern and skimmer species included in this study, Least Terns exhibited the highest reproductive success for both gull present and gull absent situations at .22/nest or 12% success. Gull-billed terns were the least successful in gull present and gull absent situations at .02/nest or .75% success. Table 3 illustrates fledging success for all study colonies in 1990 and 1991 including subtotals for gull present and gull absent colonies. Tables 4 through 7 present separate fledging success data for the four beach-nester species included in this study.

Factors that limited or prevented reproductive success in 1990 and 1991 were identified and ascribed to one of four categories: washout (w), exposure (e), confirmed gull predation (g), and undetermined factors (o). Table 8 summarizes colony losses to each of these factors for all seven study colonies.

Washout. In 1990, washouts that stemmed from storm tides on 22 May, 1 July, and 11 July seriously limited reproductive success of tern colonies on Hog Island. Colonies A and B on Hog Island lost 86 and 65% of their eggs and young respectively. No other factors that limited reproductive success accounted for any more than 13% egg and young loss in these colonies. Although the 22 May storm tide inundated all active nests on Cobb Island at that time, field work on Cobb Island did not commence until after 22 May. Since colony C on Cobb Island was unaffected by the storm tides of 1 July and 11

July, egg and chick losses to washout were not documented at colony C.

In 1991, colonies D, F, and G lost eggs and young to washout events on 20 May, 22-24 June, and 20 August. These colonies lost 22%, 6%, and 30% of their eggs and young respectively. Colony E, which was unaffected by washout in 1991, was located above the storm tide line.

Although certain colonies did not suffer any losses to washout and other colonies lost 100% of their active nests during washout events, there was no significant difference in the number of eggs and young lost to washout events between gull present or gull absent colonies (x^2 = 1.55, P< .20).

Exposure. Nest losses due to exposure were documented in colonies A, B, D, and F. Overall losses to exposure were small, and there was no significant difference in the number of eggs and chicks lost to exposure between gull present and gull absent colonies (x^2 = 2.16, P < .10). Although visitation rates to different colonies were not intentionally varied, it should be noted that colonies visited three times or more per week lost no more eggs and chicks to exposure than colonies visited less frequently.

Confirmed Predation. Confirmed losses to gull predation were few in 1990. In fact, gull present colony C actually incurred fewer losses to predation (0%) than gull absent colonies A and B (5% and 11% respectively).

In 1991, confirmed gull predation was apparent in all four colonies, and colony E lost 100% (n = 106) of its eggs and young to Herring and Great Black-backed Gulls. Gull predation for all colonies in 1991 was the single highest cause for nest failure other than the unknown category, and accounted for .74 individuals per nest or 31% of all eggs produced. Combining colonies in 1990 and 1991, confirmed gull predation was significantly higher for gull present colonies than for gull absent colonies, and the colony that suffered the greatest predation was located closer than any other colony to large numbers of nesting gulls (x^2 = 92.29, P < 0.001).

Other. By far the most eggs and young lost in 1990 and 1991 were claimed by undetermined factors ("other"). These are cases in which there is no evidence of washout, exposure, or predation at the nest or colony site. Eggs and young simply disappear from the colony. This category does not apply to cases in which there is any possibility that young birds have wandered from their nests sites and elude censusing, or that juvenile birds have fledged and left the colony.

Due to the lack of evidence pointing to the causes of nest failures in these circumstances, they have been grouped into the undetermined category rather than pigeonholed into existing categories. This is in contrast to the approach of several researchers who have studied predation on beach-nesters and considered "missing" eggs and chicks as victims of predation (Nisbet, 1975; Hulsman, 1977; Houde, 1983; Quinn and Morris,1986).

In the past, missing eggs and chicks have been assigned as "predator takes" because the lack of evidence for the cause of egg and chick disappearance is consistent with the pattern of a predator that attacks by the air and flies off with its prey without landing in the colony. This pattern could apply to predation from Fish Crows (Corvus ossifragus), Northern Harriers (Circus cyanea), Laughing Gulls, Herring Gulls, or Great Black-backed Gulls. Fish Crows and harriers were not observed at any of the study colonies in 1991, and Laughing Gulls were regularly observed only at colony G. Thus, it is likely that, if missing eggs and chicks are indeed taken by predators, Herring and/or Great Black-backed Gulls are the unknown predators.

Figures 6 through 8 illustrate the number of eggs and chicks lost to confirmed gull predation (g) , washout (w), exposure (e), and undetermined factors (o) for gull absent, gull present, and combined 1990 and 1991 tern/skimmer colonies. These figures also illustrate fledging success of these colonies.

VISUAL OBSERVATIONS: In 1990, there was no gull predation directly observed at study colonies on Hog Island or Cobb Island. On only four occasions on Hog Island and once on Cobb Island were Herring, Great Black-backed, or Laughing Gulls observed close enough to tern/skimmer colonies to elicit nest or colony defense behavior. In all four instances, these gulls were deterred by Common and/or Least Tern defense .

In 1991, gull predation was directly observed at the study colonies on one occasion. At this time, Laughing Gulls were seen taking eggs from Black Skimmer colony G the day after it incurred heavy losses to a washout event. Three eggs were taken in a span of 20 minutes, and the pressure these gulls imposed on the remaining skimmers in the colony showed no signs of abating at the conclusion of the day's observation period. Herring Gulls were also present at the colony at this time but they were not directly observed taking eggs or young from this colony.

The amount of observed gull disturbance was quantified in 1991 as a measure of the amount of time in a ten minute period that a predator caused any individual tern or skimmer to be away from its nest. This number is expressed as a percentage of the total observation time for each colony and is termed the "percentage observed gull disturbance". The highest percentages obtained coincided with periods of the greatest egg and chick loss to gulls documented from nest monitoring. The percentage observed gull disturbance was significantly higher for gull present colonies than for gull absent colonies in 1991. ($x^2 = 12.01$, $P < 0.0001$). Figure 9 illustrates the percentage of time during observations that gulls harassed terns and skimmers at their nests.

GULL ACTIVITY INDEX: Gull activity in tern and skimmer colonies was quantified in 1991 using the gull activity index. The largest numbers of gull prints per sample nest were recorded during periods of the heaviest gull disturbance that was directly observed and evidenced from nest monitoring. Gull activity indices were significantly higher at gull present than at gull absent colonies. ($x^2 = 8.95$, $P < 0.01$).

Gull prints were counted weekly, and the cumulative index derived for colonies G and F is the sum of eight weeks of sampling. Colony D was sampled for six weeks since it was not included as a study colony until two weeks of the 1991 field season had passed. Colony E was sampled for three weeks before nesting terns and skimmers deserted this colony. Thus, there was a disparity in the number of nests sampled per colony based on colony persistence. Additional variation in the number of nests sampled resulted from colony size differences. Table nine summarizes the total number of nests sampled per colony and the gull activity indices recorded per colony in 1991.

Only two gull prints were recorded along transect lines in colony G after eight weeks of sampling, and there were zero recorded in six weeks at colony D. This compares to 27 prints counted in eight weeks at gull present colony F. However, the highest counts of gull prints within colony boundaries were counted at colony E, which was directly adjacent to a gull colony. In only three weeks of sampling, 488 gull prints were recorded at colony E. The number of prints counted steadily increased as neighboring Herring Gulls moved into this colony, destroyed tern and skimmer nests, and usurped this site for their own nesting effort. The increase in gull activity at colony E over the course of three weeks is illustrated in Figure 10.

Table 3: Reproductive success of all species in all colonies in 1990 and 1991.

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colony	gull proximity	# nests	# eggs	# fledged	# fledged/nest	% fledged
A/1990	gull absent	39	59	1	0.03	2%
B/1990	gull absent	25	46	1	0.04	2%
G/1991	gull absent	151	445	1	0.01	0.20%
D/1991	gull absent	112	259	16	0.14	6%
subtotal		327	809	19	0.06	2%
C/1990	gull present	11	20	5	0.45	25%
F/1991	gull present	116	259	15	0.13	6%
E/1991	gull present	47	106	0	0	0%
subtotal		174	385	20	0.11	5%
TOTAL		501	1194	39	0.08	3%

Table 4: Common Tern reproductive success in 1990 and 1991.

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colony	gull proximity	# nests	# eggs	# fledged	# fledged/nest	% fledged
A/1990	gull absent	27	37	0	0	0%
B/1990	gull absent	16	30	0	0	0%
G/1991	gull absent	38	79	1	0.03	1%
D/1991	gull absent	42	88	7	0.17	8%
subtotal		123	234	8	0.07	3%
F/1991	gull present	59	119	0	0	0%
E/1991	gull present	43	95	0	0	0%
subtotal		102	214	0	0	0%
TOTAL		225	448	8	0.04	1.80%

Table 5: Least Tern reproductive success in 1990.

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colony	gull proximity	# nests	# eggs	# fledged	# fledged/nest	% fledged
A/1990	gull absent	12	22	1	0.08	5.00%
B/1990	gull absent	9	16	1	0.11	6.00%
subtotal		21	38	2	0.1	5.00%
C/1990	gull present	11	20	5	0.45	25%
subtotal		11	20	5	0.45	25%
TOTAL		32	58	7	0.22	12%

Table 6: Gull-billed Tern reproductive success in 1991.

Table 6: Gull-billed Tern reproductive success in 1991.

colony	gull proximity	# nests	# eggs	# fledged	# fledged/nest	% fledged
D/1991	gull absent	34	69	1	0.03	1%
F/1991	gull present	30	64	0	0	0%
TOTAL		64	133	1	0.02	0.75%

Table 7: Black Skimmer reproductive success in 1991.

Table 7: Black skimmer reproductive success in 1991.

colony	gull proximity	# nests	# eggs	# fledged	# fledged/nest	% fledged
G/1991	gull absent	113	366	0	0	0%
D/1991	gull absent	36	94	8	0.22	8.50%
subtotal		149	460	8	0.05	1.73%
F/1991	gull present	27	76	15	0.56	19.73%
E/1991	gull present	4	11	0	0	0%
subtotal		31	87	15	0.48	17.24%
TOTAL		180	547	23	0.13	4.20%

Table 8: Percentage of all eggs produced in 1990 and 1991 lost to various factors.

Table 8: Percentage of total eggs of all species produced in 1990 and 1991 lost to confirmed gull predation, washout, exposure, or other. Table includes percentage of eggs that resulted in fledged young.

colony	gull proximity	# eggs	gulls	wash.	expo.	other	fledged
A/1990	gull absent	59	5%	86%	5%	2%	2%
B/1990	gull absent	46	11%	65%	13%	9%	2%
G/1991	gull absent	445	22%	22%	0%	56%	0.20%
D/1991	gull absent	259	22%	6%	5%	61%	6%
subtotal		809	20%	24%	3%	51%	2%
C/1990	gull present	20	0%	0%	0%	75%	25%
F/1991	gull present	259	27%	30%	2%	35%	6%
E/1991	gull present	106	100%	0%	0%	0%	0%
subtotal		385	46%	20%	1%	28%	5%
TOTAL		1194	29%	23%	2%	43%	3%

Figure 6: Egg fates for 1990 and 1991 gull absent colonies.

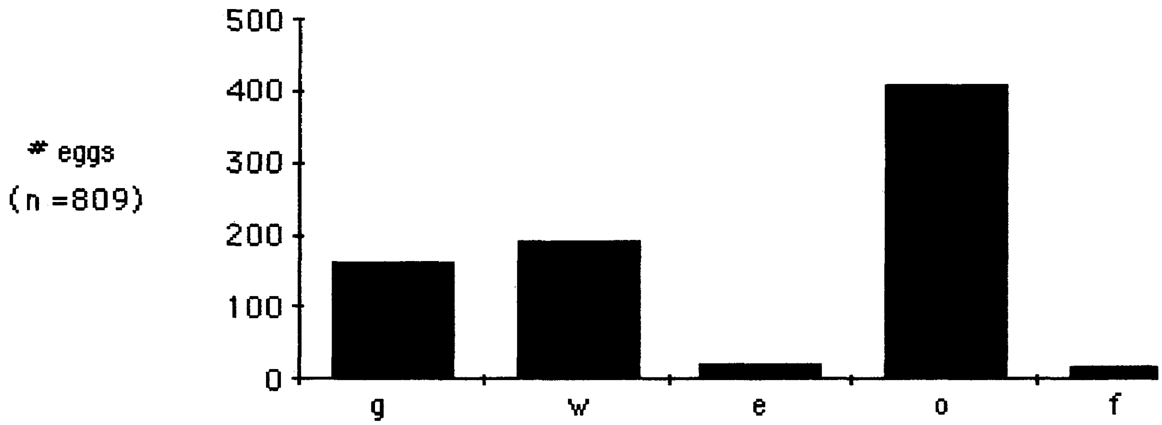

Figure 6: Egg fates for all species in 1990 and 1991 gull absent colonies. g= confirmed gull predation, w= washout, e= exposure, o= other, f= fledged.

Figure 7: Egg fates for 1990 and 1991 gull present colonies.

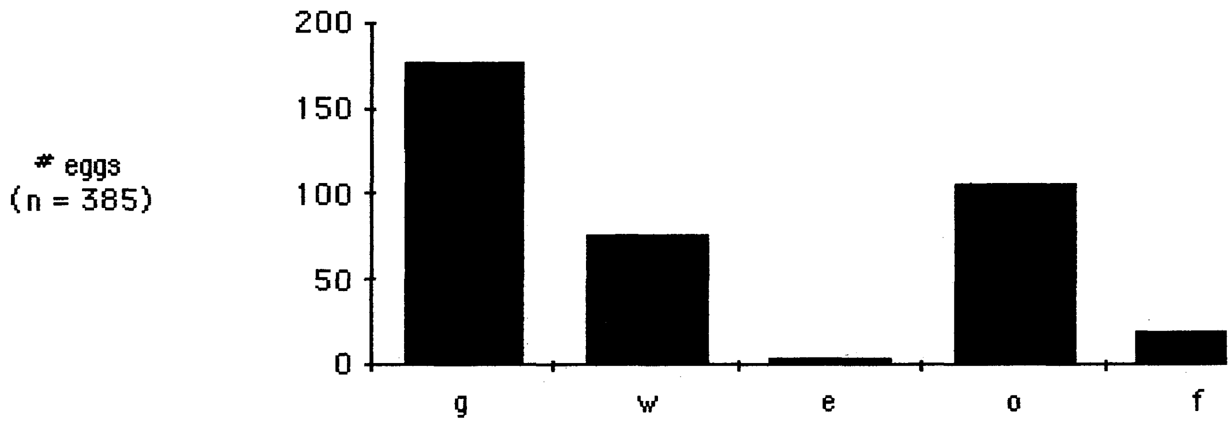

Figure 7. Egg fates for all species in 1990 and 1991 gull present colonies. See Figure 6 for symbol explanations.

Figure 8: Egg fates for all species in all colonies.

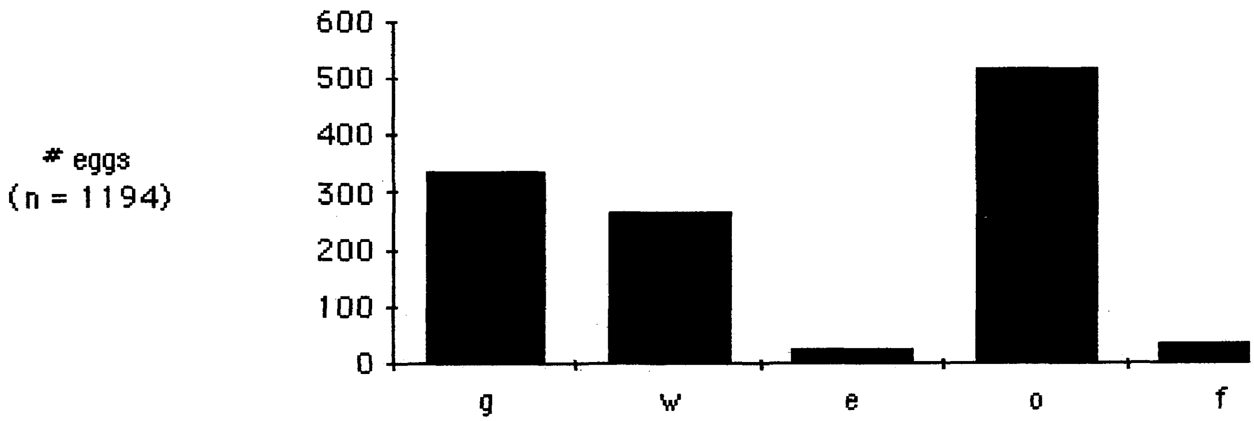

Figure 8. Egg fates for all species in all colonies. See Figure 6 for symbol explanations.

Figure 9: Percentage of observation time per colony that gulls elicited nest defense.

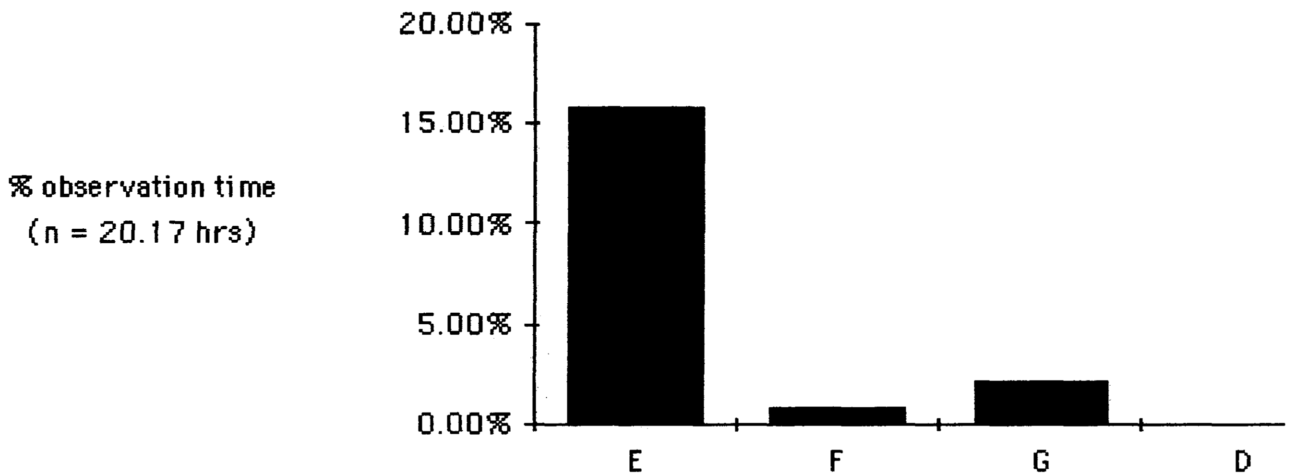

Figure 9. Percentage of observation time per colony that gulls elicited nest defense.

Table 9: Gull activity indices and the total number of nests sampled per colony in 1991.

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colony	gull proximity	total # nests sampled	gull activity index - 1991
G	gull absent	29	0.25
D	gull absent	24	0
F	gull present	37	3.38
E	gull present	6	162.67

Figure 10: Number of gull prints counted in subsequent weeks at colony E.

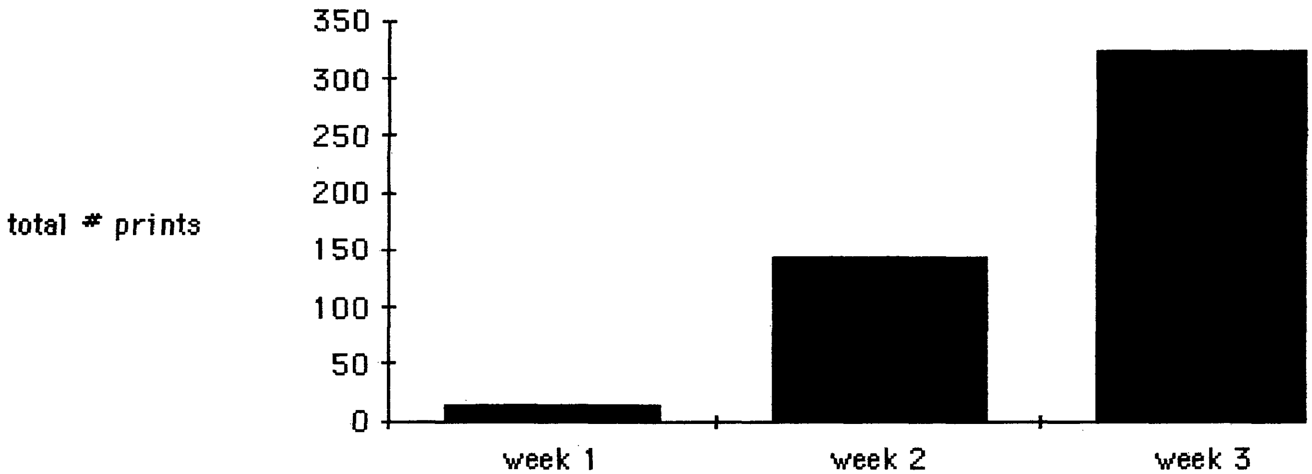

Figure 10. Number of gull prints counted in subsequent weeks at colony E.

DISCUSSION

This study presents data collected over a two year period on five islands off the Virginia Coast. Several trends are made apparent by this study that may be operating throughout Virginia or wherever colonial beach-nesting terns and skimmers face rapidly increasing gull populations.

Reproductive success (fledging success) pooled for all species in both years was low at 3% of all eggs produced (n = 1194). Three out of the four study species were found to be reproducing at a level that is below recruitment and the remaining species at a level that is approximately stable. If the reproductive success documented in this study is indicative of a long term trend for Virgina's terns and skimmers, then the future of these species as conspicuous components of Virginia's barrier island ecosystem is uncertain.

Reproductive success documented for Common and Gull-billed Terns is alarmingly low. Common Terns fledged 0.04 young per nest, or 1.8% of Common Tern eggs produced. Assuming constant fledging success, it would take each pair of Common Terns in this study approximately 50 years to replace themselves in the population. Gull-billed Terns fledged 0.02 young per nest or 0.75% of all the eggs they produced. At that rate, it would take each pair of Gull-billed Terns approximately 100 years to replace themselves. When compared to the 12 year reproductive lifespan ascribed to Common Terns (Burger and Gochfeld 1991), clearly these species are reproducing at a level below that which can sustain the current population.

Black Skimmers produced 0.13 fledglings per nest or 4.2% of all skimmer eggs produced. At this rate, each pair of skimmers can be replaced in the population in approximately 15 years, which is equal to the reproductive lifespan of the Black Skimmer reported by Burger and Gochfeld (1990). This level of reproductive success approaches that sufficient to maintain stable population size. However, since not all individuals that fledge will return to breed in their natal colony, this level of reproductive success is more consistent with a slight population decline than population stability.

Reproductive success of Common Terns and Black Skimmers in 1990 and 1991 is also low in comparison to that reported for these species on the Virginia barrier islands in 1980 and 1981. Smith (1982) provides fledging success data for Common Terns and Black Skimmers in beach habitats on Metompkin Island. Common Terns produced .99 fledglings per nest (replacement in approximately two years) and Black Skimmers produced .71 fledglings per nest (replacement in approximately three years). While there may be high variation in fledging success between colonies and seasons, this comparison may well be indicative of an overall drop in fledging success during the last decade.

Least Terns fledged .22 individuals per nest in this study, and are the only species that reproduced at a level that does not indicate a population decline. Assuming fledging success remains constant, each pair of adult Least Terns should replace themselves in the population in approximately nine years. Since the average reproductive lifespan of a Least Tern likely probably approaches the 12 years reported for Common Terns, Least Tern numbers should remain stable within the study area if fledging success remains .22 individuals per nest.

Another consistent trend evidenced throughout this study is that there is no single factor or event uniformly responsible for the low reproductive success of terns and skimmers in each colony. With the exception of exposure to extremes of temperature, all identified causes for egg and chick mortality may be considered to have a "major" impact on reproductive success. The relative number of eggs and chicks lost to washout, predation, and undetermined factors (other) varied greatly between colonies and over the 1990 and 1991 breeding seasons. Factors that consistently account for the loss of large numbers of eggs and young are apparent only when data from several colonies is pooled.

Exposure. Only 2% of all eggs produced during this study were lost due to exposure, and three of the seven study colonies did not incur any losses to exposure. It could not be determined whether losses to exposure occurred due to human disturbance that kept adults away from their nests or simply from extreme temperatures. Although most colonies were subjected to occasional disturbance from human beachgoers and at least four colonies experienced regular and heavy weekend beach use by humans, there were no documented instances of large scale exposure losses stemming from human activity. Most beachgoers observed during the course of this study avoided colonies of terns and skimmers.

Washout. The number of eggs and young lost to washout events varied between 0 and 86% of all eggs produced in a colony in a given nesting season. At times within a season, single washout events destroyed all active nests in a colony (100% of all eggs produced at that point in the breeding season). During the course of this research, 22% of all tern and skimmer eggs produced were lost to washouts. There was, however, a large difference in the percentage of eggs and young lost to washouts in 1990 and 1991. Of the 125 eggs produced in 1990, 65% were lost to storm tide washouts. This compares to 17.6% egg and chick loss to washout of the 1069 eggs produced in 1991.

The impact that washout events will have on the reproductive success of a colony in a given nesting season is dependent on the timing of washout events relative to the stage of the nesting cycle. For example, timing of washout events in 1990 coincided with critical periods in the nesting cycle for terns in this study. Generally, incubation lasts approximately three weeks for terns and skimmers. Chicks then take approximately three additional weeks to fledge. If clutches are lost, terns and skimmers are usually able to renest; however, subsequent clutches often contain fewer and/or smaller eggs than the initial clutch (Perrins and Birkhead 1983, Kaiser et al 1988). This "recycling" takes approximately five to ten days. Therefore, beach-nesters in colonies that are within the storm tide flood zone require six to seven weeks free from washout events in order to successfully raise young to fledging age.

In 1990, all tern nests on Hog and Cobb Islands were washed over during a spring high tide and a strong northeastern wind that coincided on 22 May. Since nest monitoring did not begin until after 22 May, none of the eggs and chicks lost to this event are included in this study. However, this event was important in the changes it brought about in the timing of nesting activities in 1990, and the fact that study subjects were renesting at the start of the 1990 field season. By 1 June, most birds had recycled and were initiating their second clutches of the season. "Peak hatching" of terns and skimmers occurred between 20 and 27 June. Chicks produced at this time were still less than ten days old when the second washout event, another storm with a northeastern wind, hit the barrier islands on 1 July. Approximately 60 eggs and chicks (over 90% of eggs and chicks present) on Hog Island were lost to this washout event. Some birds recycled and began to renest (the third attempt of the season) by the end of the first week of July. However, these birds were again impacted by a washout caused by an intense electrical storm on 11 July. After the 11 July washout, most terns on Hog Island aborted nesting attempts at these colony sites. A few remained to attempt a fourth clutch; however, many produced no more than a single egg and these were often dropped indiscriminately on the sand rather than placed in a well-defined nest or scrape. Eggs produced at this time would not have hatched until mid-August and young would not fledge until the first week of September. Given their late start and the fact that they would have to leave for migration so shortly after fledging, it was doubtful that any birds produced at this time would survive beyond their first month.

In 1991, the timing of washout events did not coincide as closely with critical stages in the nesting cycle, and the impact of washout events on terns and skimmers was less apparent than in 1990. Again, before the start of the field season, the barrier islands experienced a northeastern wind that coincided with the spring high tide on 20 May. No losses to washout from this event are included in this study and all 1991 information began with the first renesting attempts of terns and skimmers. After recycling during the last week of May, terns and skimmers reached peak hatching in 1991 by the third week of June. However, a strong northeastern wind that lasted from 22-24 June caused a large washout that claimed many eggs and young. Those birds that attempted a third clutch reached peak hatching by the end of the third week of July. Young hatched at this time did not face a washout event until Hurricane "Bob" hit the Virginia coast on 20 August. Thus, all chicks produced in 1991, whether products of second or third nesting attempts, had ample time to reach fledging age.

In addition to timing, the impact that washout events can have on any given colony depends on the colony site habitat parameters, particularly elevation. In 1990, colony C on Cobb Island did not experience washout because it was located above all but the 22 May storm tide line. In 1991, colony D on Metompkin Island was not damaged by the 22-24 June washout. Colony E on Cedar Extension Island did not lose any eggs or young to washout during this field season. This is in contrast to colonies A and B on Hog Island (1990) and colony G on Dawson Shoals (1991). These colonies lost eggs and young to washout events on multiple occasions due to the locations of these colonies below the level of the storm tide line.

Confirmed Predation. Predation by gulls constituted a major factor influencing the reproductive success of tern and skimmer colonies overall in 1990 and 1991. Of the three factors that were positively identified, confirmed gull predation accounted for a greater number of eggs and young that failed to fledge (29% of total eggs produced) than exposure (2%) or washout (22%). Thus, gull predation was the most important factor of those identified that limited the reproductive success of terns and skimmers in this study.

There was high variation in the amount of gull predation documented in 1990 and 1991. Confirmed gull predation in 1990 study colonies accounted for the loss of only 6% of all eggs and chicks produced. This compares to 65% egg and chick loss to washout in 1990. In 1991, losses to confirmed gull predation amounted to 31% of all eggs and chicks produced which compares to 17.6% loss to washout. Thus, gull predation clearly had a larger impact on reproductive success in 1991 than in 1990. This variation in confirmed gull predation over two seasons may be due to the variation in the effects of washouts and a disparity in the number of nests monitored over two seasons. In 1990, washouts destroyed active nests on Hog Island three times during the course of field work. In 1991, two washouts were recorded and only one of these, the June washout, had a catastrophic effect on active colonies. Thus, eggs and chicks were more consistently available to predators in 1991 than in 1990. Also, 90% of the 1194 eggs included in this study were produced in 1991. This means that a greater number of prey items were available to predators in 1991 than in 1990.

Other. Losses of eggs and young to undetermined factors amounted to 43% of all eggs produced during this study. This makes undetermined factors the most important cause of egg and young mortality. Although this information could be interpreted as a gap in the data that represents some major factor in reproductive success that has not been identified, it is likely that eggs and young that disappear from study colonies are indeed taken by predators. These data are separated from those included under "Confirmed Predation" because, other than the disappearance of eggs and young, there is no evidence in the colony that a predator has been present.

Predators could take eggs and young from a colony and leave no evidence of their visit if 1) the predators flies into the colony and takes its prey without landing, 2) the predator leaves footprints in the colony that are not detected during nest monitoring activities, or 3) the predator leaves no footprints in the colony. In addition, the low frequency at which successful predation was directly observed may be due to the possibility that predatory pressure from gulls is higher at night than during the day. It is possible that one or all of these circumstances may have occurred during this study. For example, Laughing Gulls on the wing were observed removing eggs from colony G. The gulls did not land anywhere in the colony and therefore left no evidence of their presence that could be detected during nest monitoring. Herring Gulls have been observed attempting to take eggs and young in this manner as well. Also, colony D on Metompkin Island, which lost 61% of its eggs and young to undetermined factors, was located on a hard-packed substrate of sand and shell that was less likely to contain footprints than the substrates at other colonies.

Thus while the factor(s) responsible for the disappearance of eggs and young cannot be verified with 100% confidence, the available evidence points to predation for at least some of the eggs and young. The only predators observed during 1990 and 1991 engaging in behaviors that could lead to the apparent disappearance of eggs and young were gulls. If the 43% of eggs and chicks separated into the "other" category were indeed taken by gulls, then approximately 72% of the 1194 eggs produced during this study fell victim to predaceous gulls.

Although the evidence presented above suggests that protection from predaceous gulls may help improve reproductive success experienced by terns and skimmers, it does not implicate gulls as the sole factor responsible for declines in beach-nester populations or the poor reproductive output of terns and skimmers in this study. As evidenced in the 1990 data, washout events can destroy all active nests in a colony at one time, so the importance of these events should not be overlooked.

While reproductive success of terns and skimmers in this study is low, and factors limiting that success may be neatly categorized into several groups, the third general trend evidenced from this work concerns the interaction of the factors that limit reproductive success. Of particular interest are instances where predation and washout are related in the impact they have on a colony. At colony G on Dawson Shoals, Laughing Gulls routinely approached the colony in search of unguarded eggs. Throughout early June, skimmers at this colony deterred all Laughing Gulls that approached within approximately 100 meters through active colony defense. However, after the 22-24 June washout event in which this colony lost 22% (74/343) of its eggs and young, the adult skimmers ceased colony defense against Laughing Gulls. In fact, remaining adults at the colony stood and watched as Laughing Gulls, all the while on the wing, took the remaining eggs and young that survived the washout. To these attacks, the skimmers offered no resistance except for within approximately one meter of the nest each pair attended. In one twenty minute period, Laughing Gulls were observed to successfully steal three skimmer eggs. Herring Gulls also contributed to the damage, but these birds first landed outside the colony boundaries and moved in to snatch eggs and young on foot. This heavy gull activity continued over the next few days and by 2 July, there were no more eggs or young left in this colony (269 eggs and chicks that survived the washout were taken by gulls). These observations suggests that there may be a link between catastrophic events at a colony (such as a washout) and the susceptibility of that colony to the effects of predation.

One colony that did not suffer any catastrophic events other than gull predation was colony E. This colony lost 100% of its eggs and chicks (n=106) to Herring and Great Black-backed Gulls as the gulls moved in to place nests in the area that contained the tern and skimmer nests. The first nests destroyed by gulls were noted on 13 June, and by 1 July the area that had been a Common Tern and Black Skimmer colony had been completely usurped by gulls.

The gull colony adjacent to colony E occurred in the highest parts of Cedar Extension Island, and none of these gulls suffered any damage from washout events in 1991. Likewise, the terns and skimmers that moved into the dune edge bordering the north side of this gull colony (colony E) did not experience washout. No other colonies occurred so close to an active gull colony in 1991 and no other colonies were spared from the effects of washout in 1991. This information suggests that the selection of this area as a colony site by terns and skimmers was based on the amount of habitat, limited though it was, above the storm tide line. However, gulls had already established a colony at this site before the terns arrived to breed. Eventually, the gulls succeeding in procuring this area for their nesting effort. They fed on the eggs and young produced at colony E, outcompeted terns and skimmers for nesting space, and usurped the area encompassed by colony E.

The nest site competition evidenced by these observations is clear. Furthermore, when viewed in the light of the events that took place at colony G following the June washout, the effects of this competition are magnified. Terns and skimmers may be forced to nest in marginal habitats that are more prone to washout effects because gulls have taken over the highest overwash nesting habitat. Not only may terns and skimmers be more likely to face washout losses due to nest site competition, but tern and skimmer colonies may be more susceptible to gull predation following a washout event. Thus, the presence of large numbers of gulls near beach-nester colonies forces terns and skimmers to nest in suboptimal overwash habitats, which increases the risk of losses to washouts, which increases the risk of losses to predation. The issue of competition for space between gulls and terns in Virginia is one that deserves additional study, especially considering the apparent link between competition, predation, and washout.

Events at colony E illustrate several points: First, they show how complete colony failure can be imposed on nesting terns and skimmers by predaceous gulls. Secondly, they provide evidence for the nest site competition that occurs between terns and gulls. In addition, they point to an increased risk of gull predation for tern and skimmer colonies nesting in close proximity to large numbers of nesting gulls.

In 1990 and 1991, gull predation at gull present colonies (45% of all eggs produced) was higher than for gull absent colonies (20%). However, gull present colony C on Cobb Island in 1990 did not experience any losses of eggs or young to predaceous gulls. This colony was located greater than 50m from the nearest active gull nest and was probably too small (11 nests) and cryptic to attract opportunistic visual predators such as gulls. In fact, this colony was so inconspicuous it was consistently difficult to find the nests during nest monitoring activities - even after the nests had been marked.

The gull present colonies F and E on Cedar Extension Island in 1991 both experienced high levels of gull predation. Colony F, although approximately 200m from the gull colony on this island, was a subcolony of a much larger tern/skimmer colony that was conspicuous from almost any vantage point on the island. Likewise gulls were visible at all times to birds nesting in colony F. Consequently terns and skimmers in colony F frequently engaged in nest and colony defense behaviors against gulls. Colony F lost 27% of all eggs produced to gulls, which is a higher level of gull predation than recorded at any gull absent colony (see Table 8).

Colony E lost 100% of all eggs produced to gulls. Unlike other gull present colonies in this study, individual nests in colony E were located as close as 2m to active gull nests. Results of nest monitoring indicate that tern/skimmer colonies face greater levels of gull predation when located directly adjacent to gull colonies than when merely located on the same island with gull colonies.

In addition, and in support of the assertion that nest site competition with gulls relegates terns and skimmers to nesting in suboptimal habitats, the percentage of eggs and chicks lost to washout was higher for gull absent colonies (24% of all eggs produced) than for gull present colonies (20%), although this difference is not statistically significant. While this observation may be due to the fact that eggs and young in gull present colonies are taken by gulls before they can be taken by a washout, only one of three gull present colonies experienced any losses to washout. All four gull absent colonies lost eggs and young to washout. Also, the only gull present colony with washout losses, colony F, was located in a low overwash area on the fringe of a larger tern/skimmer colony that was located on dunes above the normal storm tide lines. Therefore, the birds that nested in colony F may have selected a large colony in which to breed, but were outcompeted for optimal nest sites within that colony by other terns and skimmers.

Finally, methods were employed in this study that represent additional means to study gull predation and may lend greater consistency to future research on the predatory impacts of gulls. Although the gull activity index and the quantification of observed gull disturbance do not provide information on actual predation levels, results of the data derived from these methods agree with levels of confirmed gull predation recorded from nest monitoring activities. The highest gull activity indices were taken from colonies E, F, G, and D which is the same order for colonies that experienced the highest to lowest gull predation. Likewise, the percentage of time that gulls elicited nest defense was highest for colonies E, G, F, and D (colony G skews the order away from that found through nest monitoring due to the large amount of gull activity observed following the June washout). In addition, these methods also indicate the much higher level of gull predation that occurred at colony E compared to all other colonies. Both observed gull disturbance and the index of gull activity are substantially higher for colony E than for any other colony.

Both of these methods have advantages and disadvantages. For example, the index of gull activity can immediately convey the relative amount of pressure from gulls on foot that a colony has recently experienced. Thus, this method provides information that the researcher may not directly witness. However, this method cannot verify whether or not an egg or chick has been taken and is only useful for identifying predators that attack on foot on substrates that readily take footprints. The quantification of observed activity allows the researcher to compare directly observations recorded at different colonies and at different times. However, as with any visual observation, the behavior quantified may occur only sporadically, and the researcher may easily miss a significant event by not being present as it occurs.

The greatest value of these two methods can be realized when they are combined to quantify gull activity that is directly observed and gull activity that may take place when the researcher is not present. These methods are simple to implement and both can be performed if appropriate print-bearing substrate is present. In addition, both methods are minimally impactive to the study subjects - the quantification of observed activity is done outside colony boundaries at a distance that is not disruptive to the study subjects and the gull activity index can be performed on a colony or subcolony in approximately five to ten minutes.

The results of this study document that gull predation, although not the sole cause for declines in reproductive success, is a major factor that limits productivity of terns and skimmers on the Virginia barrier islands. Considering all the identified factors that affect reproductive success, confirmed predation by gulls accounted for more egg and chick losses than any other factor. If egg and chick losses to undetermined factors are also attributed to gulls, then gull predation was responsible for the loss of up to 72% of the 1194 eggs produced in this study. Colony washouts from storm tide flooding can also exert a major detrimental impact on reproductive success. In addition, there is some evidence that both of these factors act in concert. Nest site competition with gulls and an increased susceptibility of beach-nesters to predation following a catastrophic event contribute to the low reproductive success observed. Tern/skimmer colonies located in close proximity to gull colonies may be less likely to experience washouts, but these colonies are more susceptible to the effects of gull predation than tern/skimmer colonies that are not located near nesting gulls.

The apparent link between predation and washout is nest site competition with gulls. It is recommended that further study and management efforts be directed toward identifying that link and preventing the problem by minimizing nest site competition. Management is recommended that precludes the use of large scale gull control efforts that are monetarily prohibitive and of questionable efficacy. It is recommended that locations such as Cedar Extension, which contain abundant nesting habitat above the storm tide line but present beach-nesters with a large threat of gull predation, be managed in certain seasons as "mini-refuges" that are kept free of nesting gulls. Management of these areas might include the erection of chick shelters which have proven to decrease numbers of chicks lost to predaceous gulls (Burness and Morris 1992). Such refuges would provide large numbers of terns and skimmers with nest locations that are protected from large scale washout and gull predation. By relieving beach-nesters of these two major threats to reproductive success, productivity of Virginia's terns and skimmers should increase and the restoration of these species on the barrier islands may begin.

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