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THE COMMON TERN (Sterna hirundo) IN WESTERN LAKE SUPERIOR: HISTORY, MANAGEMENT, AND POPULATION MODELING

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This is to certify that I have examined this bound copy of a master's thesis by

William Lloyd Penning

and have found that it is complete and satisfactory in all respects,
and that any and all revisions required by the final
examining committee have been made.

Francesca J. Cuthbert

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Signature of Faculty Advisor

Date

GRADUATE SCHOOL

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William Lloyd Penning
150 words

Abstract

This thesis is divided into two parts: (1) a history of colonial waterbird management in the St. Louis River estuary, and (2) a predictive model for Common Tern populations.

The first part summarizes the history and methods of management of Common Terns in the estuary (1937-1990). Human disturbance, predation and gull encroachment were identified as primary reasons for breeding failure. Availability of nesting habitat free from human disturbance, predators and competition from gulls appears to be the most important factor influencing breeding productivity.

Population dynamics of Common Terns were explored using a deterministic model. Variables defining a stable breeding population examined included: (1) sub-adult survival rate (2) adult survival rate (3) adult reproductive rate (Mx) and (4) sub-adult reproductive rate.

This model suggests a realistic combination of variables needed to maintain a stable population is: Mx = 1.10, adult survival = 92%, sub-adult survival = 15%, and sub-adult breeding = 12.5%.

Preface

Declining populations of Common Terns (Sterna *hirundo)* in the western Great Lakes have created concern over the future of the species in this region. Of the 5 Common Tern colony sites in Minnesota, the most intensively managed site is in the St. Louis River Estuary which "straddles" the border between Minnesota and Wisconsin adjacent to Duluth Minnesota. This thesis is divided into two parts: (1) a history of colonial waterbird management in the St. Louis River (1937-1990), and (2) a predictive model for Common Tern populations.

The first part summarizes the history and methods of management of the Common Tern population in. the estuary. The majority of this information has not been published nor collated into a single report. A detailed history of management activities in the estuary is needed to clarify future conservation priorities, past successes and failures, and prevent unnecessary repetition of effort.

The breeding population of Common Terns peaked at approximately 250 pair in 1981, but declined to only 68 pairs in 1986. From the early 1980's until 1989 there was almost total nesting failure. Human disturbance, predation and gull encroachment were identified as the primary reasons for nesting failure. Efforts were initiated in 1978 to provide secure nesting habitat for terns. Management techniques used in the estuary included: attraction techniques (e.g. tern decoys, recorded tern vocalizations); discouragement techniques (e.g. Bird Scaring Reflective Tape, monofilament line, owl decoys, chasing); predator control (e.g. electric fences, removal of predators); vegetation management (e.g. herbicides, mechanical scraping) and rip-rapping to improve habitat.

Cooperation between state and federal agencies as well as numerous private firms contributed to the success of this project in an area that is characterized by private ownership and heavy use by both the public and industry. The recent successes in the estuary clearly indicate that providing secure nesting habitat is the most important factor in protecting and managing this population. Secure nesting habitat can be defined as open beach areas free from human disturbance, gull competition, and mammalian and avian predation. In the estuary this equates to islands.

My direct involvement with the St. Louis River Colonial Bird Management Program began in 1985 when I was hired by the Wisconsin and Minnesota Departments of Natural Resources to assist in field work is continued in this capacity through the 1987 field season. From 1988 through 1990 I was the Project Leader for the program. During my tenure I was intimately involved with every aspect of the program. This included: an annual gull census, a weekly tern census, discouragement and encouragement activities, coordination among government agencies contact with the media and public, predator control, vegetation management , banding, nest marking, access control, personnel issues, and report writing.

When I became the project leader I felt strongly that my job was to do whatever it took to increase Common Tern nesting success (obviously this was the goal of the resource agencies also). Often this included trying new techniques (e.g. nest boxes, Great Horned Owl control). If these techniques did not work I quickly modified or abandoned them.

To collect the background information for the history / management portions of the project prior to my tenure involved extensive literature searches in the on and the Flicker as well as reviewing MN/DNR records and discussions with MN and WI DNR personnel. Both Fred Strand (WI/DNA) and Lee Pfannmuller (MN/DNR) were very helpful in this aspect of my work. The bulk of the information on Common Terns in Minnesota is contained in unpublished MN/DNR documents. However, there have been papers published in n Colonial Waterbirds, the Passenger Pigeon and other ornithological journals that contain information on Minnesota terns. The most difficult part of writing the history/management portion of my thesis was summarizing material that was nearly three dimensional. I had to decide if the information should be organized chronologically, by site or by management method. I tried straight chronology but quickly confused reviewers because of the constant jumping from site to site that this method required. Likewise, organization by management method also required considerable spatial and time gymnastics by the reader. I finally ended up by summarizing the management techniques at each site in a roughly chronological order. I hope that this gives the reader an historical sense of the overall project and of each specific site while at the same time explaining management techniques that were tried and the context in which they were used.

In the second part I used a deterministic model to explore the population dynamics of Common Terns. The model identified variables that define a stable breeding population and examined their interactions. The variables included: 1) sub-adult survival rate 2) adult survival rate 3) adult reproductive rate (Mx) and 4) sub-adult reproductive rate. The model examined the tern population in discrete units of one year, specifically at the time of fledging.

The model suggested that when Mx = 1.10, sub-adult survival rates of 14-15% are needed to maintain a stable breeding population without causing the other variables to range outside the historical limits. A 14-15% annual sub-adult survival rate is at the a per limits of the average reported for historical data. An annual adult survival r to of 89-94% is suggested by the results of this model. When annual adult survival rates drop below 89% the sub-adult annual survival rate must exceed 16% if the population is to remain stable. Of the 4 Mx (Mx= fledging rate = number of chicks fledged per breeding pair per year) values modeled (0.90, 1.00, 1 10, 1.20) the value of 1.10 seems to fit best within the sustainable biological limits of Common Terns. Breeding by sub-adults (most likely 3 year olds) may play a significant role in offsetting the low fledging rates and high adult mortality rates that Common Terns often experience. Breeding by a small percent of s b-adults (12.5% in this model) may allow the population to withstand an occasional bad year when productivity is down or even allow for lower average adult an /or sub-adult survival.

Based on the data fro this model a likely combination for a stable Common Tern colony would be an Mx of 1.10, adult survival of 92%, sub-adult survival of 15%, and approximately 12.5% of the sub-adults breeding as successfully as the adults. In the past decade Minnesota Common Tern colonies have experienced fledging rates from, 0.00 to 1.35. Most colonies have consistent fledging rates considerably below 1.00; and statewide populations have declined dramatically. he most intensively managed colony in the state, Interstate Island, in the St. Louis River Estuary, has supported fledging rates greater than 1.10 since 1990. Unless other colonies in the state can be managed as successfully as Interstate Island, Minnesota's Common Tern population will continue to decline. However, preliminary results of a stochastic model similar in design to the deterministic model suggest that reliance on "snapshots" in time of Minnesota tern fledging rates (1984 Mx < 0.44, 1990 Mx = 1.35) can give false illusions as to the status of the population. If only 1984 data were used in decision making the conclusion may have been drawn that Minnesota's terns were doomed to extinction. Conversely, if only 1990 data were evaluated the conclusion that the population was growing may have been reached, thus giving a false sense of security about population stability.

The population modeling portion of my thesis was something that I became interested in relatively late in my career as a graduate student. I spent a considerable amount of time developing the deterministic model and a limited effort exploring stochastic models. Because Common Terns are a colonial species vulnerable to catastrophic events (e.g. predation, weather extremes) and are also dependent upon ephemeral habitats (disturbed areas with little to no vegetation) I suggest that stochastic modeling may be a more accurate way to approximate the "real life" parameters that affect breeding success and ultimately population size.

The History of Colonial Waterbird Management in the Duluth-Superior Harbor.

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Declining populations of Common Terns (Sterna hirundo) in the western Great Lakes have created concern over the future of the species in this area (Harris and Matteson 1975, Haymes and Blokpoel 1978, Davis and Niemi 1980, Davis 1983, Cuthbert et al. 1984, Morris et al. 1992). Common Tern colonies have consistently been reported at 5 sites in Minnesota since the 1970's (McKearnan and Cuthbert 1989), and one of these sites, the St. Louis River Estuary (Fig. 1), has been the focus of intensive management efforts of colonial waterbird populations since 1978. This paper summarizes the history of Common Tern and Ring-billed Gull populations in the St. Louis Rive Estuary as well as the history of site use and management efforts.

Early History

Records indicate that in the early 1930's there were probably over 2000 pairs of Common Terns nesting in Minnesota (Roberts 1936, MDNR unpubl. records). Roberts (1936) reported 580 pairs of terns nesting at Spirit and Hennepin islands in Lake Mille Lacs in 1930 and over 1000 pairs nesting at Gull Island in Leech Lake in 1933. Unpublished records (MDNR) indicate that there were 1000 pairs of terns nesting on Pine and Curry Island, Lake of the Woods, in 1932. However, breeding by Common Terns did not occur in the St. Louis River Estuary until 1937 (Table 1) when one nest was found at Sky Harbor (MDNR unpubl. records). Records of terns nesting in the estuary are incomplete until 1976. One pair nested on Minnesota Point in 1939 (Engstrom 1940), but the main colony was at Harbor (Hearding) Island in the early 1940's- 1954 (Hofslund 1952, Bronoel

1953, 1954, 1955). The majority of pairs nested at a newly created sand spit off Superior, Barkers Island, in 1956 (Finseth) 1957). There were 108 pairs at Barkers Island in 1957 (Cohen 1958). A large colony located on Minnesota Point in 1960-61 (Cohen 1960, Cohen and Cohen 1961) was probably the main colony in the harbor until the early 1970's (Harris and Matteson 1975). In 1972 there were 120 nests on recently deposited dredge spoils at the Port Terminal (H. Roberts, pers. comm. in Harris and Matteson 1975). In 1974 Harris and Matteson-found approximately 180 nests located at five different sites in the harbor, these sites were; the Port Terminal, Sky Harbor, the Minnesota Power and Light Hibbard Plant (MP&L), and North and South Islets (Harris and Matteson 1975). In 1975 Harris and Matteson were the first to warn that "the future of Common Terns (in the estuary) appears precarious". They suggested that habitat loss and degradation had the potential to extirpate the species from the estuary.

Fig. 1. Common Tern and Ring-billed Gull colony sites and management areas in the St. Louis River Estuary.

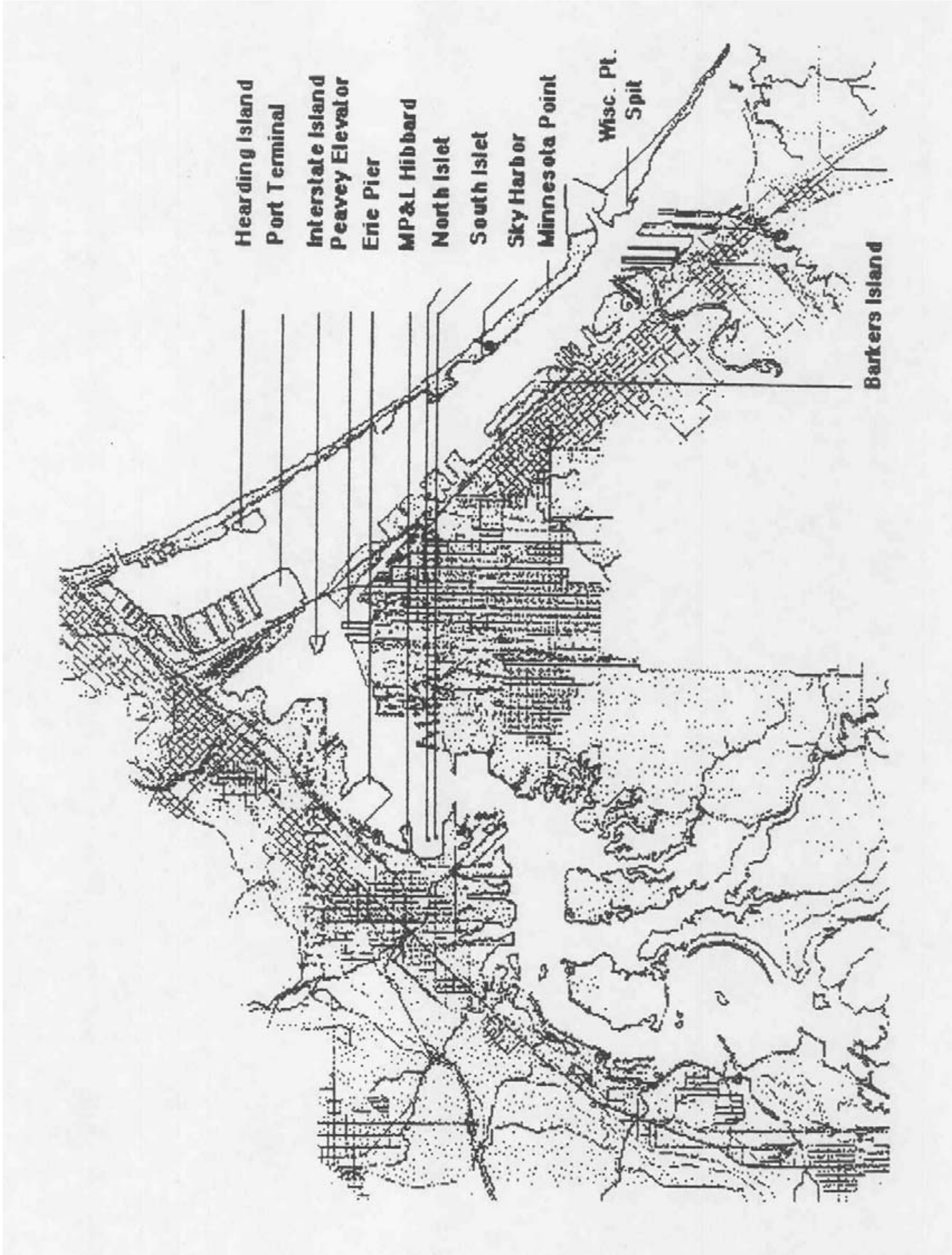

Hearding Island
Port Terminal
Interstate Island
Peavey Elevator
Erie Pier
MP&L Hibbard
North Islet
South Islet
Sky Harbor
Minnesota Point
Wisc. Pt.
Spit
Barkers Island

Table 1a. Historical records of the number of pairs of breeding Common Terns in the St. Louis River Estuary, 1937-1951. Data were obtained from the scientific literature and unpublished Minnesota Department of Natural Resources records..

	1937	1938	1939	1946	1947	1948	1949	1950	1951
Sky Harbor	**1**	**2**	**1**						
Port Terminal									
Erie Pier									
Grassy Point Islets									
Wisconsin Point									
Interstate Island									
Hearding Island				**9**	**13**	**20**	**16**	**17**	**49**
MP&L Hibbard									
Barkers Island									
North & South Islets									
Total	**1**	**2**	**1**	**9**	**13**	**20**	**16**	**17**	**49**

Table 1b. Historical records of the number of pairs of breeding Common Terns in the St. Louis River Estuary, 1952-1971. Data were obtained from the scientific literature and unpublished Minnesota Department of Natural Resources records.

	1952	1953	1954	1955	1957	1961	1963	1964	1971
Sky Harbor						3	5	3	
Port Terminal									30
Erie Pier									
Grassy Point Islets									
Wisconsin Point									
Interstate Island									
Hearding Island	33	87	52	3					
MP&L. Hibbard									
Barkers Island					108				
North & South Islets									
Total	33	87	52	3	108	3	5	3	30

Table 1c. Historical records of the number of pairs of breeding Common Terns in the St. Louis River Estuary, 1972-1981. Data were obtained from the scientific literature and unpublished Minnesota Department of Natural Resources records.

	1972	1973	1974	1976	1977	1978	1979	1980	1981
Sky Harbor	**25**	**3**	**10**	**7**	**6**	**7**	**9**	**13**	**10**
Port Terminal	**120**	**12**	**160**	**150**	**185**	**148**	**178**	**161**	**227**
Erie Pier									
Grassy Point Islets					**11**	**20**	**18**		
WisconsIn Point							**0**		
Interstate Island									
Hearding Island									
MPBL Hibbard			**10**		**4**	**3**	**5**		
Barkers Island									
North & South Islets			**9**						
Total	**145**	**15**	**189**	**157**	**206**	**178**	**210**	**174**	**237**

Table 1d. Historical records of the number of pairs of breeding Common Terns in the St. Louis River Estuary, 1982-1990. Data were obtained from the scientific literature *and* unpublished Minnesota Department of Natural Resources records.

	1982	1983	1984	1985	1986	1987	1988	1989	1990
Sky Harbor	17	29	29	79	33	0	0	0	0
Port Terminal	190	122	113	2	4	30	0	0	0
Erie Pier		24	4	1	0	0	0	0	0
Grassy Point Islets		22	0	0	0	0	0	0	0
Wisconsin Point			15	0	0	57	80	0	0
Interstate Island		0	0	50	0	0	0	81	124
Hearding Island		1	0	8	31	0	8	0	0
MP&L Hibbard									
Barkers Island									
North & South Islets									
Total	207	198	161	140	68	87	88	81	124

They also discussed the likely Ring-billed Gull population explosion and its potential impacts on the tern population (Harris and Matteson 1975). The Common Tern was officially listed as "Endangered" in Wisconsin in 1979 (Anonymous 1989) and as a "Species of Special Concern" in Minnesota in 1984 (Coffin and Pfannmuller 1988).

The first documented occurrence of breeding by Ring-billed Gulls in Minnesota was in Cook County in 1936 when a single nest was found on Lake Superior's North Shore (Thompson 1936). It was not until 1957 (Table 2) that ring-bills were recorded nesting in the estuary at Barkers Island when Cohen (1958) reported one nest within the Common Tern colony. There were no further attempts by ring-bills to nest in the estuary until 1973 when 30 nests were found at a taconite loading dock on the Minnesota side. These nests were later abandoned and no young fledged (Janssen 1974). The ring-bill population explosion began in 1974 when approximately 500 pairs were recorded at the Minnesota Power and Light Hibbard Plant (Harris and Matteson 1975). By 1977 the 1043 pairs nesting in the estuary accounted for approximately 35% of the ring-bills nesting in the U.S. portion of Lake Superior and formed the second largest colony in Lake Superior (Davis and Niemi 1980). The gull population apparently peaked in 1986 at 8361 breeding pairs. Since that time the population has fluctuated between approximately 7500 and 8250 pairs in the estuary (Penning and Cuthbert 1990b). The exact locations of the colony have varied from year to year with major sites including the Hibbard Plant, the Duluth Port Terminal and the Peavey Globe

Elevator. Currently the majority of gulls have nested at the Peavey Elevator (Penning and Cuthbert 1990a, 1990b) .

Cooperative Efforts and Management Plans

In 1975 the Arrowhead Regional Development Commission (ARDC) formed the Metropolitan Interstate Committee (MIC) to help the states of Minnesota and Wisconsin manage the St. Louis River Estuary as a single ecological unit. Because Common Terns nest on both sides of the border throughout the estuary the MIC became involved in tern management in 1978 when it initiated the development of a plan to relocate nesting Piping Plovers *(Charadrius* metodus) and Common Terns from the highly disturbed Duluth Port Terminal to other protected sites in the estuary (MIC 1978, Davis 1983).

Table 2a. Historical records of the number of pairs of breeding Ring-billed Gulls in the St. Louis River Estuary, 1957, 1973-1981. Data were obtained from the scientific literature and unpublished Minnesota Department of Natural Resources records.

	1957	**1973**	**1974**	**1976**	**1977**	**1978**	**1979**	**1980**	**1981**
Mn Power Hibbard		30	500	308	573	1227	1273	1372	1224
South Islet			2		180	361	177	153	
North Islet			2		comb.*	comb.	comb.	comb.	
Port Terminal			1		234	973	1477	2839	3747
Erie Pier									
Peavey Globe Elevator									
Interstate Island									
Grassy Point Islets					56	76	78		
Barkers Island	1								
Total	1	30	505	308	1043	2637	3005	4364	4971

* "comb." means data for North and South Islets combined

Table 2b. Historical records of the number of pairs of breeding Ring-billed Gulls in the St. Louis River Estuary, 1983-1990. Data were obtained from the scientific literature and unpublished Minnesota Department of Natural Resources records.

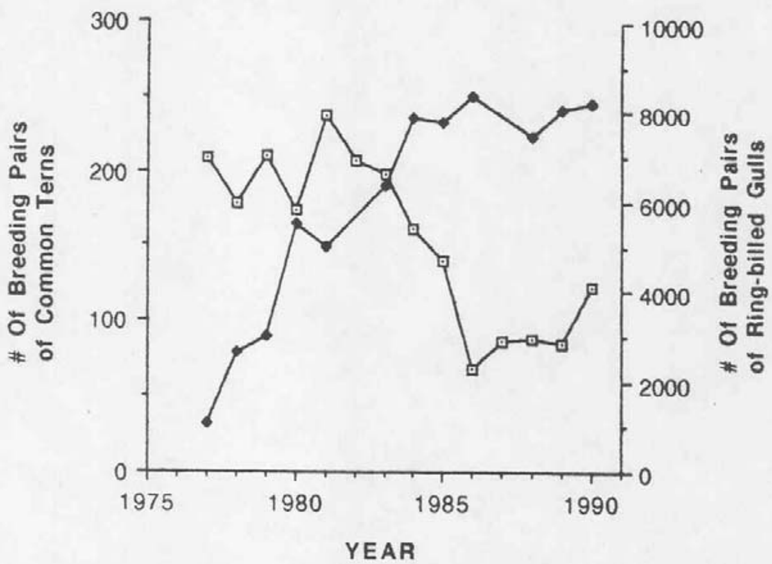
	1983	**1984**	**1985**	**1986**	**1988**	**1989**	**1990**
Mn Power Hibbard	751	762	740	392	639	1820	1395
South Islet	0	0	0	0	0	687	677
North Islet	0	0	0	0	0	570	850
Port Terminal	5608	7103	7015	7969	6828	942	0
Erie Pier	0	0	0	0	0	207	0
Peavey Globe Elevator	0	0	0	0	0	3830	4730
Interstate Island	0	0	0	0	0	0	572
Grassy Point Islets							
Barkers Island							
Total	6359	7865	7755	8361	7467	8056	8224

From development of the tern relocation plan in 1978 through the 1985 field season the MIC worked in concert with the MDNR and WDNR to implement the plan. Starting in 1983 the MDNR began coordinating the project as the St. Louis River Estuary Colonial Bird Program and has published annual reports since then. Involvement by the MIC ceased in 1986 but the MDNR and WDNR have continued the effort to present.

Census work on both gulls and terns began in 1977 (Davis and Niemi 1980); since 1980 the annual censuses have been conducted as a joint project between MDNR and Wisconsin Department of Natural Resources (WDNR). General trends for Common Terns show a stable population of approximately 190 pairs in the late 1970's with a peak of 237 pairs in 1981. In the mid- 1970's there were less than 1000 pairs of Ring-billed Gulls in the harbor; by 1977 rapid population growth was occurring. Fig. 2 shows that as the Ring-billed Gull population increased sharply the Common Tern population rapidly declined to a low of 68 pairs in 1986. Since that time the Common Tern population has slowly increased to 124 pairs in 1990 (Penning and Cuthbert 1990a). Estimates of reproductive success (McKearnan and Cuthbert 1989) of Common Terns in the estuary were made in 1982-84 and 1989-90 (Penning and Cuthbert 1990a, 1990b). Census and reproductive success estimates have provided the data base from which management decisions have been made.

The work in the estuary involved the cooperation of many state and federal agencies as well as private businesses and public utilities. Gaining the cooperation of all parties was an essential requirement for successful management of colonial waterbirds in the harbor. It is necessary to expend considerable effort on a yearly basis to ensure coordination and cooperation between each party.

Fig. 2. Historical records of the number of breeding pairs of Common Terns vs. number of breeding pairs of Ring-billed Gulls in the St. Louis River Estuary, 1977 to 1990. Data for terns are represented by open boxes and those for gulls by closed boxes. A scale in 100's of pairs of terns is given on the left vertical axis. Similar information in 1000 's of pairs of gulls is shown on the right vertical axis. Data were obtained from the scientific literature and unpublished Minnesota Department of Natural Resources records.



300
200
100
0
10000
8000
6000
4000
2000
0
1975
1980
1985
1990
YEAR
Of Breeding Pairs of Common Terns
Of Breeding Pairs of Ring-billed Gulls

Site Histories: Management and Research Efforts

Barkers Island

In the initial management plan it was decided that three sites should be secured as safe nesting habitat for terns. These sites were: Barkers Island, Herding Island, and Interstate Island. The first area set aside in the estuary for terns was a portion of Barkers Island in the city of Superior. Created by the United States Army Corps of Engineers (Corps) as a dredge spoil deposition site, this sandy, island is located at 46°43'05"N,92°03'17"W. The management area was an easement granted by the city of Superior to WDNR as mitigation for the construction of the marina on Barkers Island. Based upon recommendations from research conducted by Davis and Niemi (1980), ARDC, MIC, MDNR, and WDNR, the first actual management for Common Terns in the estuary began in 1981 when the WDNR cleared 3.2 ha. on Barkers Island. Morris et. al. (1980) suggested that vegetation control at colony sites plays an important role in increasing reproductive success at declining tern colonies. Tern decoys and recorded tern vocalizations were used at the site from 1983 to 1986 in an attempt to attract terns to the island. Both the decoys and the sound systems were modified versions of those used by Kress (1983). Unfortunately, despite management efforts, this historically active site failed to attract terns and was traded back to the city of Superior in 1987 for state ownership of a small spit on the west side of Wisconsin Point (Fred Strand, WDNR, pers. comm.).

Disturbance from an adjacent marina may have contributed to the failure of this effort.

Hearding Island

Hearding Island (46°45'31 "N,92°05'00"W) is owned by the state of Minnesota and is designated as a Wildlife Management Area. The 13.49 ha island was created by the Corps prior to 1940 as a dredge spoil deposit site. In 1983 5.2 ha were cleared of vegetation to create open sand beaches for tern nesting habitat. This was also the first year for the St. Louis River Estuary Colonial Bird Program, a cooperative effort between the MDNR, WDNR, MIC and ARDC that encouraged interstate and inter-agency cooperation. Unfortunately, habitat management met with strong local resistance as the island historically has been a recreational site for local residents and the presence of nesting terns necessitated closing the island to visitation (Penning and Cuthbert 1990b). Tern decoys and recorded tern vocalizations were used at the site from 1983 to 1988 in an attempt to attract terns to the island. Pre-season trapping of mammalian predators was conducted in 1987. However, continual harassment of nesting terns, vandalism, and predation problems (e.g. mink (Mustela vison)) strongly influenced the decision to halt management efforts on the island in 1989.

Port Terminal

The Port Terminal (46°45'15"N,92°05'45"W) is constructed of dredge spoil material which converted the original site from a wetland area to an extensive area of sand with little to no vegetation. Terns began nesting at this location in 1971; by 1974 the Ring-billed Gull population explosion in the estuary was underway and many of the gulls nested at the Port Terminal starting, in 1977. Increasing numbers of gulls, terns and Piping Plovers nested at the site in subsequent years. By the early 1980's this was the primary gull and tern colony site within the estuary.

The Port Terminal is a busy industrial area characterized by many activities that negatively impact nesting success. For example the city of Duluth stores snow on the site, there is much shipping activity in the vicinity, and fishermen, sailors, and tourists are often seen in the area. Several studies (Davis 1984, McKearnan and Cuthbert 1989) document that the combination of these activities severely limited nesting success by Common Terns. In 1984 limited discouragement activities were conducted within the dunnage area at the Port Terminal (Davis 1984). Discouragement activities in 1984 consisted of personnel chasing terns (Davis 1984). In subsequent years owl decoys, Bird Scaring Reflective Tape (BSRT), and monofilament line (Morris et al 1992) were used to supplement human. discouragement (Penning and Cuthbert 1990a). The dunnage area was used for storage and incineration of shipping containers and was determined to be unsuitable as a nesting area for terns. Full scale discouragement activities began in 1985 when intensive effort was made to prevent terns from nesting at the Port Terminal and Erie Pier (both highly disturbed industrial sites). Relative success was obtained at both Erie Pier and the Port Terminal as there were only one and two nests respectively at these sites (Davis 1985). Discouragement activities were discontinued in 1989 when the terns moved directly to Interstate Island and did not attempt to nest at the Port Terminal (Penning and Cuthbert 1990a). Concurrent with discouragement activities efforts were made to attract the terns to Hearding and Interstate Islands. In 1989 predation by Red Foxes (Vulpes vulpes) caused birds at the traditional ring- bill colony at the Port Terminal to relocate into many smaller colonies spread throughout the estuary (Penning and Cuthbert 1990a). Many of these smaller colonies caused direct conflicts with industrial activities (e.g. gulls began nesting on a warehouse loading dock). Nests were destroyed in specific areas (by permits issued to the Duluth Port Authority) and BSRT (Bruggers et al. 1986) or monofilament line (Ostergaard 1981) was strung up in these areas to discourage nesting. BSRT also was used as a discouragement technique for terns in areas where they were particularly persistent in their nesting attempts. With the break-up of the main colony at the Port Terminal, new gull colonies started at the Peavey Globe Elevator, Erie Pier, and North and South Islets. Several sub-colonies also formed at the Port Terminal and were later abandoned. No gulls or terns nested at the Port Terminal in 19901991 (F. Strand pers. comm.). The same discouragement techniques were used to a limited extent in 1988 when the colony began to expand and conflict with shipping activities.

Peavey Globe Elevator The abandoned Peavey Globe grain elevator is located in Superior, WI (46°11'37"N,92°06'23"W) and is approximately 375 m from Interstate Island. The site was never used for nesting by colonial waterbirds until

1989 when the Port Terminal gull colony dispersed. In 1989 3830 pairs of ring-bills nested at this site. The substrate consists of an area of gravel fill in a rip-rap berm. The rip-rap consists of broken slabs of concrete. During my study the gulls nested on the exposed gravel and in the rip-rap. Since 1989 Peavey has been the major gull colony in the harbor. The close proximity of this site to Interstate Island will probably lead to continued attempts by gulls to colonize the island as it is the closest available habitat for colony expansion (Penning and Cuthbert 1990b).

Wisconsin Point

In 1987 a small sand spit off Wisconsin Point (46°41'45"N,92°00'40"W) was added to the tern management area in exchange for the tern management area on Barkers Island. This site was occasionally used by terns in the early 1980's (R. Johnson, pers. comm.). The site was enclosed with a cyclone fence, to decrease human intrusion; most of the vegetation within the enclosure was removed. Decoys and recorded vocalizations were used at the site in 19881989. Because of past mammalian predation at Hearding Island and the likelihood of predation at the new Wisconsin Point site a program of trapping was initiated both prior to and during the tern nesting season. Mammalian predation can cause sudden and major pre-hatching nest mortality and its occurrence is usually unpredictable (Lemmetyinen 1973). In response to this potential threat, leg hold traps were used to remove potential predators (e.g. mink) before they caused a problem.

To discourage mammalian predators from entering the colony electric fences, similar to those used in waterfowl management areas (Lokemoen et. al. 1982), were placed around the tern colony at Wisconsin Point in 1988. Tracks in the area indicate that the electric fences discouraged white- tailed deer (Odocoileus *virginianus)* and domestic dogs (Canis familiaris) from entering the colony. ' Unfortunately, a mink avoided both the traps and the electric fence in 1988 and destroyed 20 eggs before it was removed (Penning and Cuthbert 1990b). The major problem with using an electric fence at the Wisconsin Point site was that the fence needed to extend out over the water to be effective. Because the site was often exposed to severe wave action and seiches, floating vegetation frequently became attached to the wires and grounded the fence.

Nest boxes were used at Wisconsin Point in 1989. The idea for these boxes was derived from floating nesting platforms used in Britain and Germany (Anonymous 1983, Hoeger 1988) and extrapolated to land based platforms. Before they could be fully tested, severe storms swept the entire sand spit and washed away the nest boxes and all nests both in and outside the boxes (Penning and Cuthbert 1990a) demonstrating that nest boxes are not effective at sites vulnerable to severe wave action. Since 1989 the Wisconsin Point site has been dropped from the management plan until large scale site modifications can be completed. Current plans are to build a large crib like structure of railroad ties filled with sand similar to the one constructed at the Ashland Pier site in Ashland, Wisconsin (see Matteson 1988 for a detailed description of the Ashland Pier).

Interstate Island

Securing Interstate Island (46°44'58"N,92°06'34"W) into state ownership required considerable effort because ownership was divided among Wisconsin, Minnesota, and two private corporations. The island was constructed prior to 1940 by the Corps as a dredge spoil deposition site. Negotiations to obtain easements on the 3.43 ha island from the two private concerns were initiated in 1983 and an agreement was reached in 1988 which allows MDNR and WDNR to manage the entire island for tern habitat.

Increasing availability of dredge spoil islands provided habitat for Common Terns and led to stable populations in Lake Michigan in the 1970's (Schugart and Scharf 1983). However, by the late 1970's Scharf (1981) documented that shifting dredge material deposition patterns, which allowed vegetative succession to occur, had an adverse effect on terns nesting on artificial islands in the St. Mary's River. With the cessation of dredge spoil applications to the island (probably in the 1950's), the island became dominated by Balsam Poplar (Populus balsamifera) and Eastern Cottonwood (Populus deltoides). The first removal of vegetation at Interstate Island took place in 1984 on portions of the island owned by Minnesota and Wisconsin. In 1985 50 pairs of terns nested on the island, but, Great Horned Owl *(Bubo virginianus)* predation is believed to have caused total nesting failure of this new colony. Unfortunately the entire island was not under the jurisdiction of the two states and a large portion of it remained vegetated until 1989. All vegetation was removed by scraping to expose bare sand on Interstate Island in 1989 and the north and east sides of the island were rip-rapped.

In 1989 and 1990 the entire breeding population of terns in the estuary was attracted to this bare sand site. In 1989 tern chicks (64) fledged from the harbor for the first time since 1984. In 1990 ,168 chicks fledged (Penning and Cuthbert 1990b). As a result of the habitat manipulation at Interstate the island has become an attractive nesting site for Ring- billed Gulls. Because ring- bills initiate nesting before the terns they are able to out compete the terns for limited nesting sites and gradually take over colony sites (Nisbet 1972, Morris and Hunter 1976, Davis and Niemi 1980, Courtney and Blokpoel 1983, Maxwell and Smith 1983, Davis 1983, Miller 1987). Although gull encroachment was not yet a problem on the island, a policy of gull nest destruction was initiated in 1990 to prevent it from becoming so (Penning and Cuthbert 1990b). Nest removal efforts are initiated early in the season with a goal of discouraging nesting by gulls before a tradition of nesting on Interstate Island is established.

Sky Harbor Airport

Terns were recorded nesting intermittently at Sky Harbor Airport (46°43'23"N,92°02'37"W) as early as 1937. Typical of other larid colonies in the estuary the site consists of sand fill. Because of vegetation encroachment, the site was considered to be marginal tern habitat by the mid-1970's (Davis and Niemi 1980) . Furthermore, there was a history of owl and mammalian predation at the site and terns often roosted on the runway and created a potential hazard to incoming and outgoing air traffic. Tern discouragement activities were carried out at Sky Harbor Airport from 1986 through 1989. BSRT and Great Horned Owl decoys were used to keep terns from establishing nests in the blow-outs along the shoreline and in between the runway and taxiway. After the birds began using Interstate Island in 1989 it was no longer necessary to discourage tern use at Sky Harbor.

Erie Pier

Erie Pier (46°44'43"N,92°08'37"w) is a contaminated dredge spoil disposal site still under construction by the Corps. Although gulls and terns have attempted to nest at the site in the past, nests always were abandoned early in the season. Physical disturbances (e.g. washouts and heavy equipment activities) have caused the abandonments. Because terns had nested unsuccessfully at this continuously disturbed location in 1983, limited discouragement activities began in 1984 and lasted through 1989. Despite occasional breeding attempts Erie Pier has never been an important colony site.

Minnesota Power *and Light*

The Minnesota Power and Light Hibbard Plant (46°44'07"N,92°08'54"Mi) has been an important colony site for ring-bills since at least 1974. Common Terns attempted to nest here in 1974, 1977-1979 (MDNR unpubl. records). Three chicks fledged in 1974 (Harris and Matteson 1975), efforts in later years were unsuccessful. No management activities have occurred at the site other than the annual census.

North (46°43'57"N,92°09'22"Mn and South (46°43'52"N,92°09'21 "Mi) Islets were used by ring-bills in the late 1970's and again in 1989-1990. The largest number of breeding pairs (1527) was recorded in 1990. The only nesting by terns occurred in 1974 when 9 pairs were recorded (MDNR unpubl. records). Both of these tiny islands provide secure but limited nesting habitat for larids.
The Grassy Point Islets (46°43'28"N,92°08'54"Mn had small tern populations in 1976-1979 and again in 1983 but have not been used since that time.

Conclusions

The recent successes at Interstate Island clearly indicate that providing secure nesting habitat is the most important factor in protecting and managing this population. Secure nesting habitat can be defined as open beach areas free from human disturbance, gull competition, and mammalian and avian predation. In the estuary this equates to islands; specifically Interstate Island.

In 1989 the terns moved directly to Interstate Island and did not attempt to nest at the Port Terminal. Since 1989 Interstate Island has become the most secure and successful nesting habitat for terns in the estuary. To date attempts to establish colonies at Hearding Island, Barkers Island and Wisconsin Point have failed.

On Hearding Island the cover formed by woody vegetation magnifies the predation problem. Human disturbance is also a major problem at this site. To make Hearding Island suitable for nesting Common Terns all woody vegetation would need to be removed and human access strictly controlled. Both of these requirements are not politically feasible at this time. For unknown reasons terns were never attracted to the management site on Barkers Island. As a result of the lack of interest by the terns, Barkers Island was traded to the City of Superior for a portion of Wisconsin Point and a specified amount of work that was performed by the city at the Wisconsin Point tern management area.

The most attractive habitat for Common Terns at Wisconsin.Point lies in,a zone where nest washouts are frequent. Washouts can be avoided by altering the habitat so that the best areas for tern nests are considerably above the washout zone. Currently the best option is to build a crib-like structure for the terns similar to the one at the Ashland Pier. This site also needs to be protected from predation by aggressive pre-nesting season predator control programs.

Partially cleared islands, electric fences near the water, and nest boxes have not been effective. However, discouragement and attraction techniques have been successful and may have accelerated the relocation of the terns to areas where they have been successful in producing young. Providing secure open nesting habitat by totally clearing vegetation from isolated islands has been the most effective management technique.

Interstate cooperation between Minnesota and Wisconsin has been essential in managing the Common Terns in the estuary. Furthermore, the cooperation of local residents and business is necessary to prevent human! tern conflicts.

Despite good tern reproductive success in 1989-1990, management and monitoring efforts need to continue for at leas a decade in the St. Louis River Estuary to decrease the probability of population decline. Efforts should focus on: (1) vegetation control, (2) prevention of gull nesting in prime and traditional tern nesting sites, (3) predator control, and (4) estimation of number of breeding pairs and chicks fledged per breeding pair. Although these activities should be directed at the current active site (Interstate), individuals in charge of field work should be prepared to change their conservation practices and the focus of their work if tern nesting site preference changes.

References

Anonymous. 1989. Endangered and Threatened Species List. Wisconsin Department of Natural Resources - Bureau of Endangered Resources. Madison, WI.

Anonymous. 1983. Rafts for terns. Parks. 8(1): 22.

Bronoel, J. K. 1953. Harbor Island census --1953. Flicker 25: 111.

Bronoel, J. K. 1954. Census of Harbor Island in St. Louis Bay --1954. Flicker 26: 118.

Bronoel, J. K. 1955. Census of Harbor Island in St. Louis Bay --1955. Flicker 27: 174.

Bruggers, R. L., et. al. 1986. Responses of pest birds to reflecting tape in agriculture. Wildl. Soc. Bull. 14: 161-170.

Coffin, B. and L. Pfannmuller. 1988. Minnesota's Endangered Flora and Fauna. University of Minnesota Press, Minneapolis.

Cohen, R. R. 1958. Common Tern colony on Barker's Island, St. Louis Bay. Flicker 30: 39.

Cohen, R. R. 1960. A study of Harbor Island, Duluth. Flicker 32: 73-75.

Cohen, R. R., and S. B. Cohen. 1961. Second year study, Harbor Island, Duluth. Flicker 33: 111-113.

Courtney, P. A., and H. Blokpoel. 1983. Distribution and numbers of Common Terns on the lower Great Lakes during 1900-1980: a review. Colon. Waterbirds 6: 107-120.

Cuthbert, F. J., J. E. McKearnan and T. E. Davis. 1984. Status of Common Terns nesting at the Duluth Port Terminal 1982-83. Loon 56: 20-24.

Davis, T.E. 1983. St. Louis River Estuary Colonial Bird Program. 1983. Report to the Minnesota Department of Natural Resources. St. Paul, Minnesota.

Davis, T.E. 1984. St. Louis River Estuary Colonial Bird Program. 1984. Report to the Minnesota Department of Natural Resources. St. Paul, Minnesota.

Davis, T.E. 1985. St. Louis River Estuary Colonial Bird Program. 1985. Report to the Minnesota Department of Natural Resources. St. Paul, Minnesota.

Davis, T. E. and G. J. Niemi. 1980. Larid breeding populations in the western tip of Lake Superior. Loon 52: 3-14.

Engstrom, H. 1940. 1939 Minnesota nesting records. Flicker 12: 12.

Finseth, O. A. 1957. A new Common Tern colony. Flicker 29: 39.

Haymes, G.T. and H. Blokpoel. 1978. Seasonal distribution and site tenacity of the Great Lakes Common Tern. Bird Banding 49: 142-151.

Harris, J. T. and S. W. Matteson. 1975. Gulls and terns nesting at Duluth. Loon 47: 70-77.

Hoeger, S. 1988. Schwimmkampen: Germany's artificial floating islands. J. Soil and Water Conserv. 304-306.

Hofslund, P. B. 1952. 1952 census of Knife Island. Flicker 24: 162-163.

Janssen, R. 1974. Ring-billed Gull nesting at the Port Terminal, Duluth. Loon 46:175-176.

Kress, S. W. 1983. The use of decoys, sound recordings, and gull control for re-establishing a tern colony in Maine. Colonial Waterbirds 6: 185-196.

Lemmetyinen, R. 1973. Breeding success in Sterna paradisaea Pontopp. and S. hirundo L. in southern Finland. Ann. Zool. Fennici 10: 526-535.

Lokemoen, J. T., et. al. 1982. Electric fences to reduce mammalian predation on waterfowl nests. Wildl. Soc. Bull. 10: 318-323.

Matteson, S. W. 1988. Wisconsin Common Tern recovery plan. Wisconsin Endangered Resources Report 41. Bureau of Endangered Resources. Wisconsin Department of Natural Resources. Madison, WI.

Maxwell, G.-R., and G. A. Smith. 1983. Nest site competition and population estimates of island nesting Common Terns, Ring-billed Gulls, and Herring Gulls in the St. Lawrence River. Kingbird 33: 19-25.

Metropolitan Interstate Committee. 1978. Land use and management plan for the Duluth- Superior harbor.

Miller, J. H. 1987. A study of aggressive interactions in a mixed land breeding colony in Minnesota. PhD. Thesis. University of Minnesota.

McKearnan, J. E., and F. J. Cuthbert. 1989. Status and breeding success of Common Terns in Minnesota. Colonial Waterbirds 12: 185-190.

Morris, R. D., and R. A. Hunter. 1976. Factors influencing desertion of colony sites by Common Terns *(Sterna hirundo).* Can. Field- Nat. 90: 137-143.

Morris, R. D., I. R. Kirkham, and J. W. Chardine. 1980. Management of a declining Common Tern colony. J. Wildl. Manage. 44: 241-245.

Morris, R. D., H. Blokpoel, and G. D. Tessier. 1992. Management efforts for the conservation of Common Tern *Sterna hirundo* colonies in the Great Lakes: Two case histories. Biol. Conserv. 60: 7-14.

Nisbet, I.C.T. 1972. Disaster year for terns. Man and Nature. December, 1972.

Ostergaard, D. E. 1981. Use of monofilament fishing line as gull control. Prog. Fish-Cult. 43(3): 134.

Penning, W. L., and F. J. Cuthbert. 1990a. St. Louis River Colonial Bird Program. 1989. Report to the Minnesota Department of Natural Resources. St. Paul, Minnesota.

Penning, W. L. and F. J. Cuthbert. 1990b. St. Louis River Colonial Bird Program, 1990. Report to the Minnesota Department of Natural Resources. St. Paul, Minnesota.

Roberts, T. S. 1936. The Birds of Minnesota. University of Minnesota Press, Minneapolis.

Scharf, W. C. 1981. The significance of deteriorating man-made island habitats to Common Terns and Ring-billed Gulls in the St. Mary's River, Michigan. Colonial Waterbirds 4: 155-159.

Schugart, G.W. and W.C. Scharf. 1983. Common Terns in the Northern Great Lakes: current status and population trends. J. Field Ornithol. 54: 160169.

Thompson, M. 1936. Minnesota nesting record of the Ring-billed Gull. Flicker 8: 50.

A Population Model for the Common Tern

Sterna hirundo

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Declining populations of Common Terns *(Sterna hirundo)* have created concern over the future of the species in the western Great Lakes (Harris and Matteson 1975, Haymes and Blokpoel 1978, Davis and Niemi 1980, Davis 1983, Cuthbert et al 1984) as well as other portions of eastern North America (Nisbet 1978, Kress et al 1983). Records indicate that in the early 1930's there were probably over 2000 pairs of Common Terns nesting in Minnesota (Roberts 1936, MDNR unpubl. records). Since that time the Common Tern population in the state declined to approximately 881 pairs in 1984 (McKearnan and Cuthbert 1989) .

This paper explores the population dynamics of the Common Tern using a simple spreadsheet model. Successful population management is often dependant on understanding the interactions of critical components affecting populations. Additionally, models can help to refine management areas plus they define and delineate areas of needed research (Starfield and Bleloch 1991).

Although there is a large body of literature which reports various aspects of population demographics in Common Terris there have been few actual models constructed that use all population parameters in concert to predict the requirements for a stable breeding population or predict future population trends.

Austin (1942) and Austin and Austin (1956) used lifetables to calculate yearly adult survival rates of 71-75% and predicted that at least 20% of fledged chicks must return to breed at age 4. However, Nisbet (1978) pointed out errors in their calculations and methods, re-examined their data and disputed their conclusions. Nisbet's (1978) own calculations estimate annual adult survival at 87% with 10% of fledged chicks surviving to enter the breeding population. Both the Austins and Nisbet have worked at tern colonies that are in long term decline (Nisbet 1973). Therefore these populations may be under constraints different from those of a stable population (DiCostanzo 1980).

DiCostanzo (1980) modeled population parameters from a stable colony. He estimated an annual adult survival rate of 92% with 14.3% of fledglings returning to breed at age 4. The Austins, Nisbet and DiCostanzo were unable to estimate breeding success of terns less than 4 years old. However, each indicated that juveniles comprised a small portion of the breeding population and were most likely less successful than adults at fledging chicks.

McKearnan (1986) used data from Austin and Austin (1956), Nisbet (1978) and DiCostanzo (1980) in conjunction with data she collected to predict the fate of Common Terns in Minnesota. She predicted extirpation of Common Terns from Minnesota by 2011 if reproductive rates stayed as she estimated (0.15) and the population acted according to the unpublished model she employed. A reproductive rate of 1.10 has been recognized as being sufficient to maintain a stable breeding population (Nisbet 1978, DiCostanzo 1980). This is consistent with the results reported here.

This model identifies variables defining a stable breeding population and examines their interactions. The variables examined include survival rates for adults and sub-adults, fledging rates, and the contributions and impacts of sub-adult breeding.

The next step in the analysis procedure is to ask what happens if only some of the years are good and reproduction is not at a constant rate (as assumed in the deterministic model)? And if only some of the years are good how many must be good (e.g. 1 good year in 3?) and what must the reproductive rate (Mx) be in order to have a stable population? These questions are touched upon, but not explored in depth, in the stochastic model presented at the end of this paper.

Methods

I constructed a simple deterministic model using the Microsoft Excel (version 1.5) spreadsheet (Microsoft Corporation, 1988). Variables of the model included: (1) sub-adult survival rate (2) adult survival rate (3) sub-adult reproductive rate and (4) adult reproductive rate. The model examines the tern population in discrete units of one year, specifically at the time of fledging. Clutch size and hatching rates are unimportant in the sense that only fledglings "count" (i.e. the resolution of the model does not "see" eggs or hatchlings). This model assumes there is no emigration or immigration into the population.

The model can be expressed mathematically as follows:

F(t+i) = BS4(t+i) + E(bAs(t+1) +... bAi2(t+t))~ St(W) = Ft, S2tt+l) = Sit, S3tt+t) =

S2t, S4(t+t) = qtS3t, A5(t+t) ° mtSat, Axtt+1 > = mtAxt

Whereas: F = fledglings (0 yr. olds), SX = sub-adults (1-4 yr. olds), Ax = adult (5-12 yr. olds), t = this year, (t+1) = next year, b = adult fledging rate, f3 = sub-adult fledging rate, qt = sub-adult survival rate, mt = adult survival rate.

Therefore, the total population for (t+1) = Fft+t I + S f (t+t) + S2(t+t) + Ss(t+t) + S4(t+1) + A5(t+l) + Ag(t+t) + ...A12(t+1).

The term "sub-adult" is defined as a bird less than three years old, "adult" refers to a bird four years old or older. Three year olds are a special case. They are probably sub-adults, but they will be considered as adults from a survival perspective, i.e. their survival is the same as adult survival. However, three year olds, in this model, are breeding as adults. Survival rates for terns less than four years old cannot be determined for each year because in many cases terns do not begin breeding until they are four years old (Nisbet 1978) and therefore cannot be trapped. Sub-adult survival rates are lumped as "survival to age three" which is defined as survival from fledging until they are three years old (the beginning of their fourth summer). Adult survival rates are also lumped from age four to age eleven, breeding birds older than eleven comprise a small segment of the total breeding population (Austin and Austin 1956). Reproductive rate (Mx) is defined as average number of fledglings/ pair/ year and varies between sub-adults and adults with adult reproductive rate always being a constant for all year classes of adults (i.e. Mx for a five year old is exactly equal to that of a ten year old). Sub-adult survival rates are lumped so that there is only one survival rate for the 0-3 year olds. In some cases 0°r6, 12.5%, 25%, or 37.5% of the three year olds are breeding.

Adult and sub-adult survival rates and Mx values were obtained from my research, the literature, or are hypothetical. Sub-adult survival rates were increased from 10 to 20% in increments of 1%. Mx values were increased from 0.90 to 1.20 fledglings per pair for adults in increments of 0.10. Three year old sub-adults did not breed (Mx =0% of adult Mx), bred with 12.5%, 25%, 37.5% (Mx =12.5%, 25%, 37.5% of adult Mx respectively) or bred with half the success of the adults (Mx = 50% of adult Mx). An Mx = 50% of adult Mx is equivalent to either half of the three year olds breeding just as successfully as adults or all of the three year olds breeding but only half as successfully as the adults. Using these initial parameters adult survival was adjusted until the population growth rate (Lamda) reached 1.00 (a stable population) in all trials.

A simple random model was constructed to create variations in breeding success from year to year. My experience is that the success rate in Common Terns is either very high or very low. I therefore decided to model an extreme case of this.

The random model used the same parameters as the deterministic model with the following changes. Sub-adult survival was fixed at 15%, adult survival was fixed at 92%. There were no three year olds breeding in this model. A random number generator was installed into the model to create yearly Mx variations as follows: There was a 50% chance of an Mx of 2.20 (a very high reproductive rate) and a 50% chance of an Mx of 0.00 (total nesting failure), thus the long term average for the model should be an Mx of 1.10.

Results

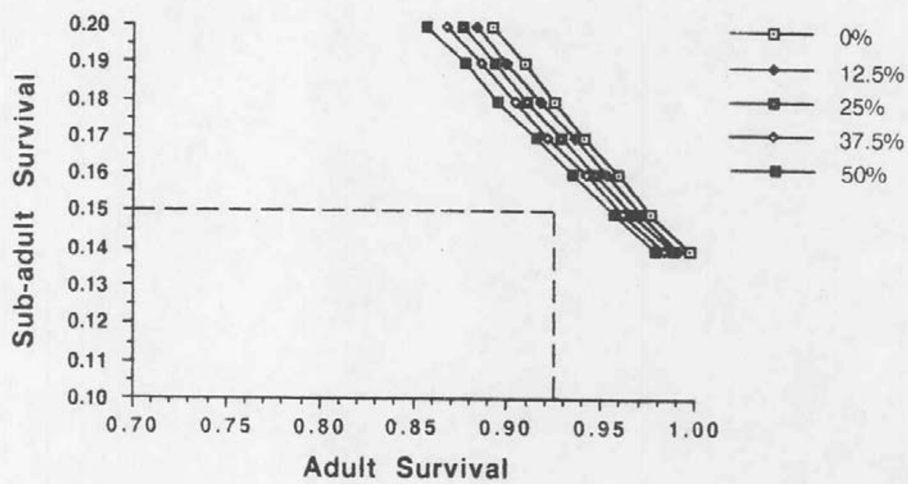
Figures 1-4 show adult survival vs. sub-adult survival for various Mx values and differing percentages of sub-adults breeding for a stable breeding population. The dashed lines in Figures. 1-5 represent the upper limits of historical data as recorded by other authors (Austin 1942, Austin and Austin 1956, Nisbet 1978, DiCostanzo 1980). Figure 5 is part of the data from Figures 1-4 represented in a different manner.

<u>Survival rates needed to maintain a stable breeding population:</u>

The predictive capacity of the deterministic model for various values of Mx was examined to see if reasonable results could be obtained using model forecasts. Compared to previously recorded long-term average adult and sub-adult survival rates, none of the predicted values falls within the limits of historical data when Mx is 0.90 (Fig. 1). Figure 2 shows that when sub-adult survival rates are 15% adult survival rates must be in excess of 92.5°r6 for an Mx of 1.00.

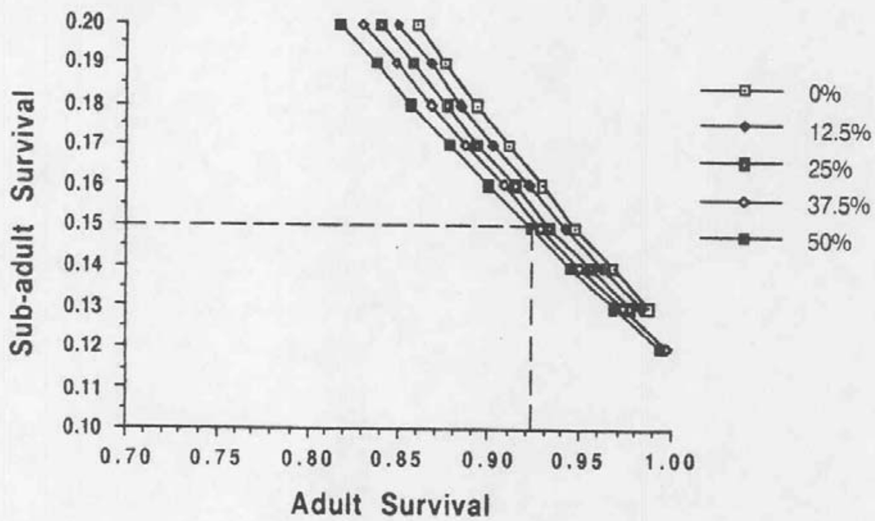
In Figure 3 sub-adult survival rates as low as 13.5% or adult survival rates as low as 89% become possible. When the sub-adults breed the survival rates of both adult and sub-adult terns necessary for a stable population do not need to be as great (Fig. 4).

Figure 1. Sub-adult survival as a function of adult survival in Common Terns in a stable breeding population. The fledging rate is held constant at (Mx=0.90). Five curves depicting different contributions of sub-adult breeding are plotted. The dashed line represents the limits of available historical data.



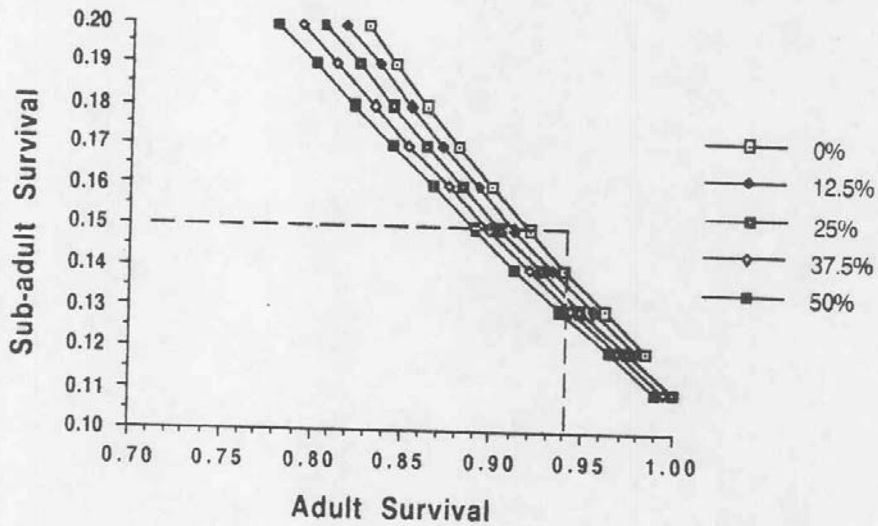
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
Sub-adult Survival
0.70
0.75
0.80
0.85
0.90
0.95
1.00
Adult Survival
0%
12.5%
25%
37.5%
50%

Figure 2. Sub-adult survival as a function of adult survival in Common Terns in a stable breeding population. The fledging rate is held constant at (Mx=1.00). Five curves depicting different contributions of sub-adult breeding are plotted., The dashed line represents the limits of available historical data.



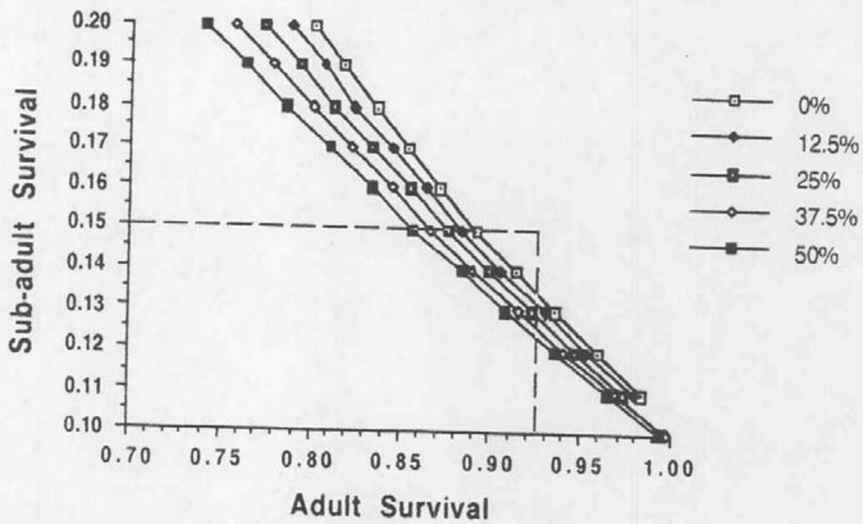
Sub-adult Survival
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.70
0.75
0.80
0.85
0.90
0.95
1.00
Adult Survival
0%
12.5%
25%
37.5%
50%

Figure 3. Sub-adult survival as a function of adult survival in Common Terns in a stable breeding population. The fledging rate is held constant at (Mx=1.10). Five curves depicting different contributions of sub-adult breeding are plotted. The dashed line represents the limits of available historical data.



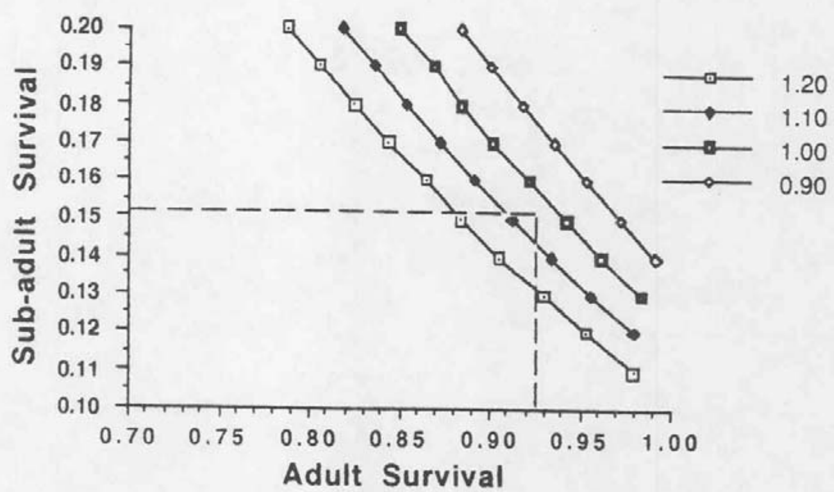
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
Sub-adult Survival
0.70
0.75
0.80
0.85
0.90
0.95
1.00
Adult Survival
0%
12.5%
25%
37.5%
50%

Figure 4. Sub-adult survival as a function of adult survival in Common Terns in a stable breeding population. The fledging rate is held constant at (Mx=1.20). Five curves depicting different contributions of sub-adult breeding are plotted. The dashed line represents the limits of available historical data.



0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
Sub-adult Survival
0.70
0.75
0.80
0.85
0.90
0.95
1.00
Adult Survival
0%
12.5%
25%
37.5%
50%

Figure 5. Sub-adult survival as a function of adult survival in Common Terns in a stable breeding population. The contributions of sub-adult breeding are held constant at (12.5%). Five curves depicting different fledging rates are plotted. The dashed line represents the limits of available historical data.



0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
Sub-adult Survival
0.70
0.75
0.80
0.85
0.90
0.95
1.00
Adult Survival
1.20
1.10
1.00
0.90

Reproductive rates (Mx needed tg maintain a stable ool latiow

Figures 1-4 suggests that as Mx increases dependance upon a large number of sub-adults breeding becomes less important. When long term Mx values of 0.90 occur the population is not able to maintain itself (Fig. 1). For an Mx of 1.00 (Fig. 2) there must be 50% of the sub-adults breeding before the predicted values fall within the range of historical values and then they are in the outer limits. An Mx of 1.10 (Fig. 3) is the lowest Mx value at which it is not necessary for sub-adult terns to breed to maintain a stable population. For an Mx of 1.20 (Fig. 4), a stable population can be maintained with 0% of the sub-adults breeding, and sub-adult survival can be as low as 14% or adult survival can be as low as 89%. Figure 5 shows adult vs. sub-adult survival for various Mx values when 12.5% of the sub-adults are breeding. Mx values of both 1.10 and 1.20 fall within historical limits.

Effects of sub-adult breeding:

Figures 1-4 suggest that breeding by sub-adults can make a positive contribution to the breeding population. Generally, as the percent of sub-adults breeding increases the adult and sub-adult survival necessary to maintain a stable population is decreased. Figure 1 shows that for an Mx of 0.90 and 50% of the sub-adult terns breeding the predicted values for adult and sub-adult breeding fall outside the historical data. The 50% sub-adult breeding predicted line falls just inside the historically recorded average survival rates when Mx is 1.00 (Fig. 2). The 37.5% sub-adult line falls just outside the historic data. If 50% of the sub-adults are breeding the adult and sub-adult survival rates necessary to maintain a stable breeding population are closer to those recorded in historic times.

When Mx is 1.10 all of the examined possibilities of sub-adult breeding (0%50%) fall within the limits of historically recorded data as suggested by Figure 3. When Mx is as high as 1.20 there are a large number of possible survival scenarios where breeding by sub-adults is not required at all (Fig. 4). In both Figures 3 and 4 stable populations can be reached without any breeding by sub-adults. The trade off is that higher Mx values are necessary to maintain a stable population.

When only 12.5% of the sub-adults are breeding the required sub-adult and adult survival rates necessary to maintain a stable population are slightly lowered. This suggests a proportional relationship between sub-adult and adult survival rates. Figure 5 presents the same data as Figures 1-4 from a different perspective.

Random Model

In the deterministic model the effects of an assumed initial population were insignificant after 30 years. Fluctuations due to starting population size no longer affected the model outcome,. In the random model it was therefore decided to look at the results only after the first thirty years.

Figure 6 is an example of the output from a single replicate which runs from year 30 through year 100 and does not include the stabilization period. The fitted line is indicated in the figure and shows that in this one example terns can have many poor years interspersed with a few good years and still maintain a stable or slightly increasing population provided the long term average value of Mx does not drop below 1.10.

However Figure 6 is only one replicate. After 100 runs of 100 years each I found that 72% of the time the ending population at year 100 was less than the initial population. This suggests that variance does lead to bias towards population reduction. The random effect built into the model reduces the chances for long term population stability. However, looking at only the ending population may lead to incorrect conclusions. In Figure 6 the ending population is clearly less than the initial population yet the population is, in the long term, actually slightly increasing.

Discussion

<u>Sub-adult Survival</u>

The difficulty in measuring sub-adult survival until the time of breeding (Austin 1953) forces most authors to lump all age categories of juveniles into one sub-adult category until the terns reach the age when they begin to return to breed in numbers large enough to be measured (at approximately 4 years old). Estimates of sub-adult survival rates to 4 years range from 10-19.5% (mean = 14%) (DiCostanzo 1980). My model suggests that when Mx = 1.10, sub-adult survival (to age 4) rates of 14-15% are needed to maintain a stable breeding population without causing the other variables to range outside the historical limits. A 14-15% annual sub-adult survival rate is at the upper limits of the average reported for historical data. However, sub-adult survival must be estimated from mark recapture studies based on trapping breeding birds on the nest. Sub-adult terns tend to initiate nesting later in the season (Nisbet 1978, Nisbet et al 1984.) and may often be biased against (Nisbet et al 1984) or missed by trapping efforts (Nisbet 1978). The difficulties associated with estimating sub-adult survival may lead to an under-estimation of the true subadult survival rate.

Adult Survival

Adult survival rates in other studies varied from 75-92% (Austin and Austin 1956, Nisbet 1978, DiCostanzo 1980).. DiCostanzo (1980) reported a 92% adult survival rate at Great Gull Island which had a stable population for several years previous to the time of data collection. Nisbet (1978) reported an annual adult survival rate of 79-83% in a declining tern colony in Massachusetts. An annual adult survival rate of 89-94% is suggested by the results of this model. When annual adult survival rates drop below 89% the sub-adult annual survival rate must exceed 16% if the population is to remain stable.

Reproductive rates (Mx) needed to maintain a stable pl ulationR

Of the 4 Mx values that I modeled (0.90, 1.00, 1.10, 1.20) the value of 1.i0 seems to fit the model best when viewed from the standpoint of what is sustainable within the biological limits of Common Terns. Reported fledging rates from the literature vary between 0 and 2.5 chicks per pair (Gochfeld and Ford 1974, Langham 1972, Nisbet 1973, DiCostanzo 1980, Nisbet et al 1984, McKearnan and Cuthbert 1989, Burger and Gochfeld 1991) under various conditions of colony stability. At the Ashland Pier Common Tern colony in Ashland Wisconsin fledging rates varied between 0.12 and 1.30 (Matteson et. al. unpubl. manuscript).

In Minnesota, McKearnan and Cuthbert (1989) found fledging rates to vary between 0.06 and 0.43 in 1984. Low fledging rates such as these indicate a declining population. However, in 1989 the Hennepin Island colony had a fledging rate of 1.19 and in 1990 the Interstate Island colony fledged 1.35 chicks per pair (Penning and Cuthbert 1990a, 1990b). If statewide management efforts can continue to produce fledging rates at or above 1.10 then the data from this model indicate that Minnesota's Common Tern population will remain stable or even increase in numbers.

While an Mx of 1.20 is certainly possible (Nisbet et.al. 1984, found an Mx of 2.5, one of the highest reported) an Mx of 1.10 seems to be more sustainable on a long term basis. Both DiCostanzo (1980) and Nisbet (1973) found average Mx values of approximately 1.10. When Mx values are less than 1.10, the adult survival rates, sub-adult survival rates and/or breeding rates begin to range outside the historical limits for this species.

Effects of Sub-adult Breeding

I was unable to find any studies that attempted to estimate the size of sub-adult breeding populations. My literature review found vague references indicating that "many" (Austin 1942, Austin and Austin 1956) Common Terns begin breeding at the age of 3. Nisbet et al (1984) documented breeding by 2-yearold Common Terns in Massachusetts. Given that the number of breeding sub-adults has gone virtually unknown it can be assumed that this number is probably quite small. Furthermore, the data from Nisbet et al (1984) suggest that productivity of terns 2-4 years old was much lower than that of older birds. However, the data presented in this paper suggest that breeding by sub-adults can make an important contribution to the stability of the population.

Breeding by sub-adults (most likely 3 year olds) may play a significant role in offsetting the low fledging rates and high adult mortality rates that Common Terns often experience. Breeding by a small percent of sub-adults (12.5% in this model) may allow the population to withstand an occasional bad year when productivity is down or even allow for lower average adult and/or sub-adult survival. In this model when 12.5% of the sub-adults are breeding there can be an approximately 1.0% lower.adult or 0.5% lower sub-adult survival rate when Mx =1.10.

The reliability of the three dependant variables (Sub-adult survival, MX, and Sub-adult breeding) is influenced by the ability to obtain accurate field data (i.e. the measurability) which influences the availability of references in the literature. Sub-adult survival and sub-adult breeding are both difficult to measure, but, sub-adult survival has been estimated from several banding studies (DiCostanzo 1980, Nisbet 1978) while only vague references are made to sub-adult breeding. Consequently I consider sub-adult survival as a "more reliable" (i.e. more data are available for comparison with my results) variable than sub-adult breeding. The Mx values are the easiest of the three variables to measure and subsequently have the widest body of literature.

Adult survival, the independent variable in this model, can be compared with many studies and thus is used as an independent check upon the effectiveness of the manipulations of the three dependent variables of the model as they interrelate with each other.

Random Model

Data from the random model show considerable yearly fluctuations in population size. Field biologists must often use only one or two years of data to draw conclusions. This can lead to incorrect assumptions and conclusions. For example predictive data from the random model (Fig. 6) suggest that even though the population may fluctuate wildly in the short term (e.g. years 35-40) in fact the long term forecast for the population is stable or slightly increasing. Management based strictly on short term data may result in the expenditure of considerable time and effort that could better be allocated elsewhere.

The example presented previously of two "snapshots" in time of Minnesota tern fledging rates (1984 Mx < 0.44, 1990 Mx = 1.35) illustrates the value of routine population monitoring and long term management plans. If only the 1984 data were used in decision making the conclusion may have been drawn that Minnesota's terns were doomed to extinction. Conversely, if only the 1990 data were evaluated the conclusion that the population was growing may have been reached, thus giving a false sense of security about population stability.

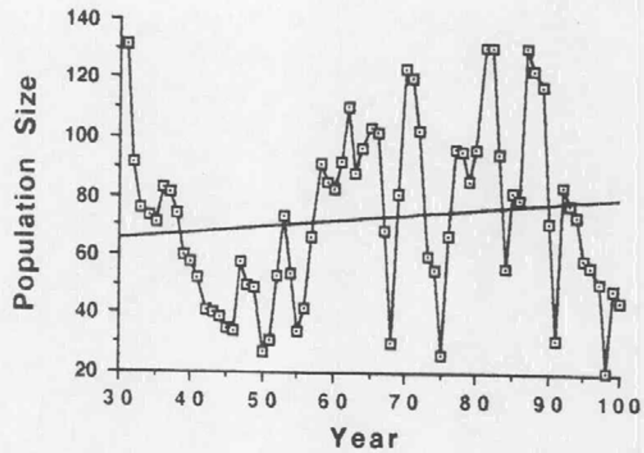
Currently the future of terns in Minnesota is uncertain. Data collected over the past 60 years indicate long term population declines (McKearnan and Cuthbert 1989). Recent management efforts are paying off with increased fledging rates (Penning and Cuthbert 1990b). However, moderate short-term successes may lead to a reallocation of resources away from tern management and thus set the stage for future population declines if management efforts are ceased before the population has reached a stable, self sustaining status.

Conclusions

Based on the results of this modeling effort a likely combination .of variables needed to maintain a stable Common Tern colony is: Mx = 1.10, adult survival = 92%, sub-adult survival of 15%, and approximately 12.5% of the sub-adults breeding as successfully as the adults. In the past decade Minnesota Common Tern colonies have experienced fledging rates from, 0.00 to 1.35. Most colonies have consistent fledging rates considerably below 1.00; statewide populations have declined dramatically. The most intensively managed colony in the state, Interstate Island, in the St. Louis River Estuary, has supported fledging rates greater than 1.00 since 1990 (F. Strand pers. comm.) Unless other colonies in the state can be managed as successfully as Interstate Island Minnesota's Common Tern population will continue to decline.

Further study using stochastic modeling techniques will probably shed additional tight on the biology of Common Terns, a species adapted to ephemeral nesting habitats and periodic total breeding failure. The random modeling exercise points out the need for a more thorough examination of the questions; (1) How often do "good" years have to occur to offset the "bad" years? and (2) Just how good do the "good" years have to be to ensure long term population stability?

Figure 6. Population size as a function of year in Common Terns based on data generated in the random model. Best fit is represented by the horizontal line. Sub-adult survival fixed at 15%, and adult survival fixed at 92%. No three year olds breeding. Long term average Mx = 1.10.


Population Size
140
120
100
80
60
40
20
30
40
50
60
70
80
90
100
Year

References

Austin, O.L., Sr. 1942. The lifespan of the Common Tern (Sterna hirundo). Bird Banding 13:159-176.

Austin, O.L., Sr. 1942. The migration of the Common Tern (Stern hi n) in the Western Hemisphere. Bird Banding 24: 39-55.

Austin, O.L. and O.L. Austin, Jr. 1956. Some demographic aspects of the Cape Cod population of Common Terns (Sterna hir . Bird Banding 27: 55-66.

Burger, J. and M.,Gochfeld. 1991. The Common Tern: Its Breeding Biology and Social Behavior. Columbia University Press, New York.

Gochfeld, M. and D.B. Ford. 1974. Reproductive success of Common Terns on Jones Beach, Long Island, New York, in 1972: a hurricane year. Proceedings Linnean Society of New York 72: 63-76.

Cuthbert, F. J., J. E. McKearnan and T. E. Davis. 1984. Status of Common Terns nesting at the Duluth Port Terminal 1982-83. Loon 56: 20-24.

Davis, T.E. 1983. St. Louis River Estuary Colonial Bird Program. 1983. Report to the Minnesota Department of Natural Resources. St. Paul, Minnesota.

Davis, T. E. and G. J. Niemi. 1980. Larid breeding populations in the western tip of Lake Superior. Loon 52: 3-14.

DICostanzo, J. 1980. Population dynamics of a Common Tern colony. Journal of Field Ornithology 51: 229-243.

Harris, J. T. and S. W. Matteson. 1975. Gulls and terns nesting at Duluth. Loon 47: 70-77.

Haymes, G.T, and H. Blokpoel. 1978. Seasonal distribution and site tenacity of the Great Lakes Common Tern. Bird Banding 49: 142-151.

Kress, S.W., E.H. Weinstein, and I.C.T. Nisbet. 1983. The status of tern populations in the northeastern United States and adjacent Canada. Colonial Waterbirds 6: 84-106.

McKearnan, J.E. 1986. Status and Breeding Success of Common Terns in Minnesota: A Thesis. Unpublished MS Thesis. Minneapolis, Minnesota, Univ. of Minnesota.

McKearnan, J.E., and F. J. Cuthbert. 1989. Status and breeding success of Common Terns in Minnesota. Colonial Waterbirds 12: 185-190.

Microsoft. 1988. Microsoft Excel Version 1.5. Microsoft Corporation. Redmond, WA.

Langham, N.P.E. 1972. Chick survival in terns, with particular reference to the Common Tern. Journal of Animal Ecology 41: 385-395.

Nisbet, LC.T. 1973. Terns in Massachusetts: present numbers and historical changes. Bird Banding 44: 27-55.

Nisbet, I.C.T. 1978. Population models for Common Terns in Massachusetts. Bird Banding 49: 50-58.

Nisbet, I.C.T., J.M. Winchell, and A.E. Heise. 1984. Influence of age on the breeding biology of Common Terns. Colonial Waterbirds 7: 117-126.

Penning, W. L., and F. J. Cuthbert. 1990a. St. Louis River Colonial Bird Program. 1989. Report to the Minnesota Department of Natural Resources. St. Paul, Minnesota.

Penning, W. L., and F. J. Cuthbert. 199015. St. Louis River Colonial Bird Program. 1990. Report to the Minnesota Department of Natural Resources. St. Paul, Minnesota.

Roberts, T. S. 1936. The Birds of Minnesota. 1936. University of Minnesota Press, Minneapolis.

Starfield, A.M. and A.L. Bleloch. 1991. Building models for conservation and wildlife management. 2nd edition, Burgess International Group, Edina, MN.