MARINE ORNITHOLOGY

Vol. 22 No. 2 1994

WATER TEMPERATURE AND THE REPRODUCTIVE SUCCESS OF CASPIAN TERNS *STERNA CASPIA* AT LAKE ST LUCIA, SOUTHEASTERN COAST OF AFRICA

D.P. CYRUS & S. McLEAN[1]

Coastal Research Unit of Zululand, Department of Zoology, University of Zululand, Pvt Bag X1001, KwaDlangezwa 3886, South Africa

[1]*Current address: Meander, P.O.Box 112, Himeville 4585, South Africa*

Received 1 September 1992, accepted 7 September 1993

SUMMARY

CYRUS, D.P. & McLEAN, S. 1994. Water temperature and the reproductive success of Caspian Terns *Sterna caspia* at Lake St Lucia, southeastern coast of Africa. *Marine Ornithology* 22: 193-203.

The effects of a substantial drop in water temperature, during a cold spell, on the fish fauna and breeding success of Caspian Terns *Sterna caspia* at Lake St Lucia were investigated. The immediate and direct short-term effect of this episodic event was a massive fish kill, whereas the indirect and potentially more serious long-term effect was for Caspian Terns to abandon their breeding attempt due to a lack of food. Replacement clutches produced during the same season also failed. Although absolute determinations could not be made regarding the long-term effects of the breeding failure of the largest colony of Caspian Terns in southern Africa, this study shows that episodic events of this nature affect a wide spectrum of the aquatic ecosystem and that not all interactions are noticeable at the time the event occurs. It also shows that the need exists for monitoring to be undertaken immediately after an event of this nature so that both the short- and long-term effects on the fauna may be more clearly understood.

INTRODUCTION

Spatial and temporal variations in physical and chemical conditions are characteristics of estuaries. The probable effects of these fluctuations on the biota have long been recognized but their implications are not always completely understood. Particularly important in this regard are the impacts of rapid changes in the environment, because these may have far greater effects on the biota than do more gradual changes. In addition they may also have long-term effects. Two important perturbations in this regard which can be considered as episodic events, are; rapid changes in salinity brought about by exceptionally high flood levels, and sudden drops in water temperature which accompany unusually cold weather.

This paper forms the fourth in a series dealing with episodic events and estuaries. The first by Cyrus (1988) investigated the effects of cyclonic

flushing on the benthic fauna and the diet of the fish *Solea bleekeri* in the estuarine Lake St Lucia on the south east coast of Africa. A second (Forbes & Cyrus 1992) reviewed the broader impacts, related to salinity change, of a major cyclone on the same system, and the third (Martin *et al.* 1992), investigated the effects of cyclonic flushing on the ichthyoplankton of the St Lucia Estuary. This paper provides data on an indirect effect in part of the ecosystem which was caused by an unusual drop in water temperature.

The effect of sudden temperature changes on land, particularly temperature decreases, are well known. The effect of temperature shock is primarily and obviously biological and more apparent on land where dead organisms are easily visible. In water, temperature-induced mortalities might be less obvious or might only be detected at a later stage when conditions have changed again and the cause of death is no longer obvious. In addition to identifying direct effects of an episodic event, it is important to understand indirect effects which may operate on varying time scales. Little is known of the long-term biological consequences of extreme, but natural, physical events in estuaries.

STUDY SITE AND METHODS

Lake St Lucia (28° 23'S, 32° 36'E) on the south east coast of Africa covers an area of some 325 km^2 and is the largest estuarine lake in Africa (Fig. 1). The largest colony of Caspian Terns *Sterna caspia* in southern Africa, comprising some 61% of the subregional breeding population (Cooper *et al.* 1992), nests on two islands (Lane and Bird) in Lake St Lucia (Fig. 1). Their main breeding season extends from May to mid-September, although in recent years the birds have attempted to breed during the summer months as well (pers. obs.).

As part of an ongoing study of the breeding success of the Caspian Tern population at Lake St Lucia, the colonies were visited during the breeding season of the winter of 1987 from May through to September with counts being made of the number of nests, eggs and chicks present. During this period a spell of cold weather occurred that resulted in a massive fish die-off in the lake. As such die-offs are uncommon in the St Lucia System, a survey of mortalities was conducted over the period 20 to 25 June, by the staff of the Natal Parks Board (NPB). They undertook a series of 11 beach walks totalling 1070 m, at selected sites spread around the lake, to count the number of dead fish and record the species which had been affected. In order to relate fish deaths and tern breeding data to the events of the cold spell, temperature data from two weather stations near St Lucia; the Futululu Forest Station (12 km west of St Lucia Estuary) and Graded Sands (2 km west of Charters Creek) (Fig. 1) were reviewed. Data from the latter station included hourly temperatures.

RESULTS

Weather conditions

Data from the Graded Sands Station showed that the weather during the first half of June 1987 was typical for the Zululand coast with the mean daily maximum air temperature being 25.8°C and the mean minimum 10.0°C (mean maximum & minimum for June over the past 17 years = 23.6 & 10.6°C). The maximum daily temperatures recorded ranged from 18.4 to 31.9°C and minimum from 6.6 to 16.0°C.

The mean hourly temperature over the period 10 to 18 June 1987 was 17.4°C, but cold windy conditions set in on 19 June causing a rapid drop in air temperature with the mean hourly temperature dropping by some 7 to 9°C (Table 1) to a mean of 12.5°C over the following four days. The minimum daily temperature fell from a mean of 9.5°C over the previous nine days to 3.2°C on 22 June while the mean daily maximum temperature remained below 20°C. From 24 June, temperatures started to increase again with

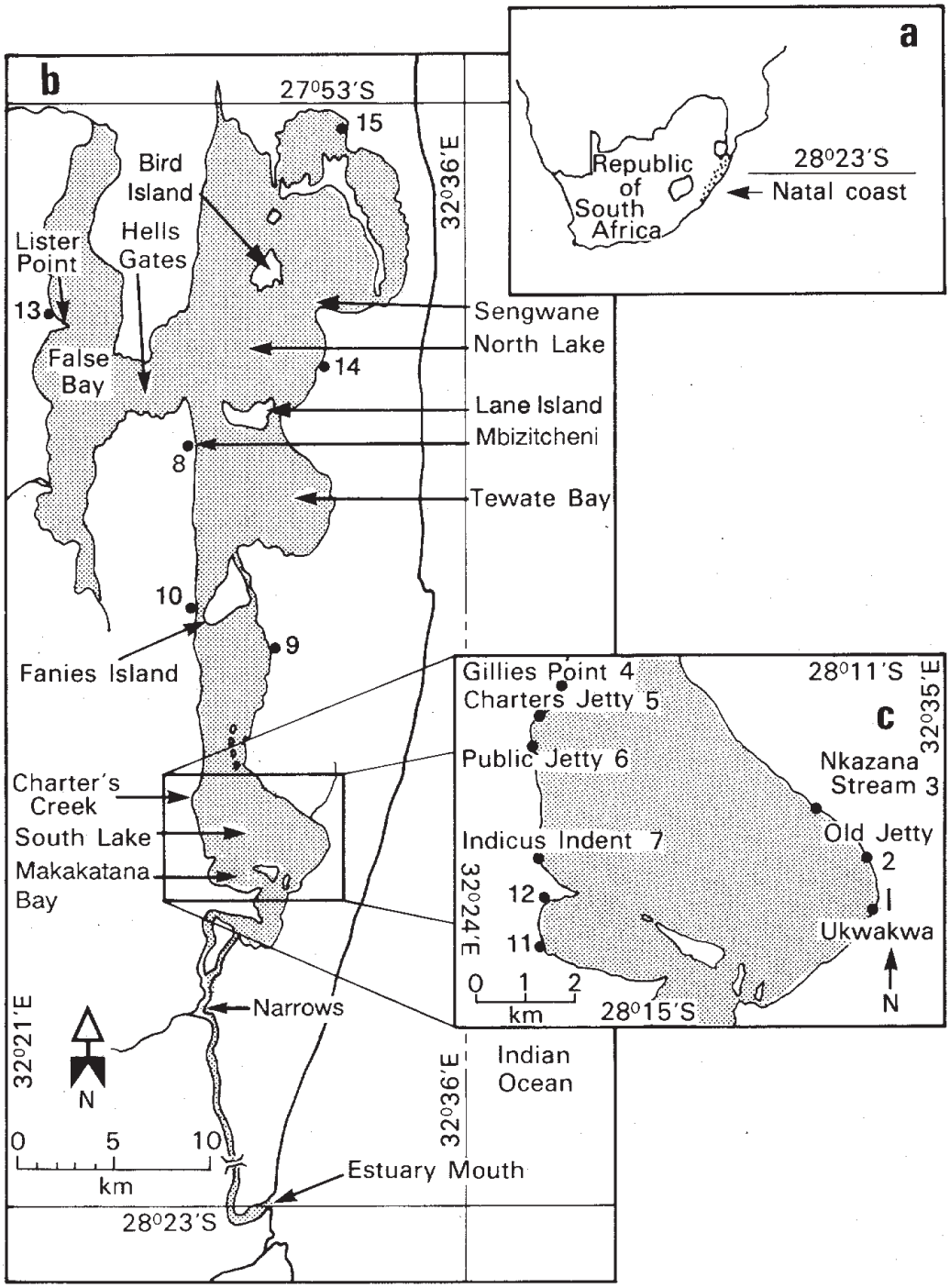

Figure 1

Study site; (a) in relation to southern Africa, (b) the St Lucia system, (c) South Lake; 2, 4, 5, 9, 10, 11, 12, 13, 14 & 15 = sites at which shoreline counts of dead fish were made (see Table 1).

TABLE 1

MEAN HOURLY, MAXIMUM AND MINIMUM TEMPERATURES AT GRADED SANDS STATION AND MAXIMUM AND MINIMUM TEMPERATURES FOR FUTULULU RESEARCH STATION (TEMPERATURE IN °C; TEMP = TEMPERATURE; MAX = MAXIMUM; MIN = MINIMUM; SD = STANDARD DEVIATION

Locality	Graded Sands				Futululu R.S.	
Date	Mean hourly	SD	Max	Min	Max	Min
10.06.87	16.9	5.5	25.7	8.0	24.2	9.9
11.06.87	17.7	5.4	28.3	6.6	24.8	14.7
12.06.87	18.5	3.1	25.2	14.6	23.0	14.4
13.06.87	15.8	3.7	22.5	9.0	18.4	7.0
14.06.87	15.8	6.0	24.7	6.1	23.0	13.1
15.06.87	16.9	4.8	26.3	9.7	24.4	7.4
16.06.87	17.3	5.1	26.5	8.8	24.7	8.4
17.06.87	17.8	4.1	25.7	10.7	23.9	12.9
18.06.87	20.2	5.7	31.9	12.1	28.4	11.4
19.06.87	13.3	2.1	18.6	9.9	13.6	8.4
20.06.87	11.4	1.4	15.5	9.9	10.9	5.5
21.06.87	13.0	4.5	21.9	7.0	15.1	5.5
22.06.87	12.1	6.6	23.7	3.2	20.0	4.6
23.06.87	15.4	6.0	24.7	5.6	22.6	9.4
24.06.87	17.0	4.6	26.1	9.7	23.7	10.1
25.06.87	---------- No Data ----------				24.9	9.4
26.06.87	---------- No Data ----------				25.7	11.0

the mean daily maximum for the last seven days of the month being over 23.0°C.

Water temperatures are not normally monitored at Lake St Lucia. However, between 17 April 1977 and 1 August 1979 Bickerton (1989) recorded maximum and minimum water temperatures at Charters Creek on 42 occasions. The minimum water temperatures (range 10.5 to 27.0°C) were compared with the minimum air temperatures (range 7.8 to 27.0°C), recorded on those days at the Graded Sands weather station, using a regression analysis with a linear model of $y=a+bx$. The results were highly significant ($y=12.1+0.50x$: $P=<0.005$: $r=0.684$). Applying this regression to the minimum air temperatures recorded for the period over the 1987 spell of cold weather (Table 1) indicated that water temperatures reached a low of at least 13.7°C. Because this is a directly calculated regression value it is possible that the temperatures may have been even lower.

Effects of the temperature drop on the fish fauna

On 20 June, the first dead fish were washed ashore at South Lake between Old Jetty and Nkazana Stream (Fig. 1, sites 2 & 3). Dead fish were

collected from a 20-m section at Old Jetty, yielding 91 fish of eight species as well as a cuttlefish *Sepia officinalis* (Table 2). A further eight fish species and a prawn *Penaeus monodon* were found on adjacent sections of beach. Three species were dominant in the fish kill, *Hilsa kelee*, *Leiognathus equula* and *Thryssa vitrirostris*. On the same day NPB staff covered approximately 1.4 km of shoreline between Old Jetty and Nkazana Stream collecting dead fish for the crocodile farm. Although numbers were not recorded a total of 416 kg of fish was collected with *H. kelee* dominating.

Between 20 and 25 June the 1070 m of shoreline searched yielded a total of 770 fish, giving a mean of 0.7 fish per metre (range 0.1 to 16.6 fish/m). With a shoreline of about 347 km (Begg 1978) the total number of fish which were killed may have exceeded 250 000. A total of 21 species was found dead during the survey period (Appendix A). However, three species made up 91% of the total number recorded. These were *H. kelee* (33.3%), *T. vitrirostris* (30.6%) and *L. equula* (28.8%). Standard Length (SL) of several specimens collected was measured, where this was done the recorded ranges are given in Appendix A. A feature of this die-off was that the vast majority of fish killed were small species, with both the adults and juveniles of larger species being notably absent.

Nesting activities of Caspian Terns during the winter of 1987

Details of the 1987 breeding season are summarized in Table 3. The first nest was recorded on 28 May and by 14 June there were 42 nests containing 63 eggs on Lane Island and 16 on Bird Island with 23 eggs, all being about one week old. The islands were visited again on 18 July, 25 days after the four- day cold spell (Table 1). Based on the date of the previous visit and the fact that incubation in this species is 20 to 22 days (Maclean 1985), it was expected that after natural mortalities some 60 to 70 chicks would be present on the two islands but only 35 were located. However, a mass relaying of clutches had occurred approximately 10 days previously, with 66 nests (95 eggs) on Lane Island and 63 nests (102 eggs) on Bird Island.

The following visit on 1 August was planned so that chicks from the new clutches would be one-week old. It was found that the number of adults present on both islands had dropped dramatically (Table 3). In addition there were only six clutches still being incubated on Lane Island and two on Bird Island. There were clear indications that the bulk of clutches at each colony had been abandoned, including some 80 eggs on Lane and 95 on Bird Island. Many of the clutches were still in the nest scrapes but cold, while others had been pecked open by Greyheaded Gulls *Larus cirrocephalus*. Only 12 chicks were found, five of which had been ringed during the visit of 18 July. By 18 August there were no nests or chicks left on Bird Island with none being left on Lane Island by 21 August (Table 3).

Courtship was recorded on Lane Island on 21 August and it appeared that a further breeding attempt was about to take place with one clutch being found on 8 September. This did not materialize because early and heavy summer rains flooded the islands. Lane Island was almost completely covered by 8 September, and Bird Island was totally under water by 28 September by which time the Caspian Terns had all moved away. No further breeding attempts occurred until January 1988 and these were also flooded out.

DISCUSSION

Fish kills and water temperature at Lake St Lucia

TABLE 2

SPECIES AND DENSITIES OF FISH KILLED DURING THE COLD SNAP OF JUNE 1987 AT SELECTED SITES AROUND LAKE ST LUCIA (SEE FIGURE 1)

Locality	Old Jetty	Dead Tree Bay (A)	Dead Tree Bay (B)	Fanies Island	Gillies Point	Makakatana Bay	Makakatana Stream	Charters Creek	False Bay	Ngema Stream	Selleys Lakes	Total
Site No. (Fig.1)	2	9	9	10	4	11	12	5	13	14	15	
Date	20 Jun	23 Jun	23 Jun	23 Jun	23 Jun	23 Jun	23 Jun	22 Jun	22 Jun	25 Jun	25 Jun	-
Distance surveyed (m)	20	100	10	100	50	50	20	100	400	20	200	1070
Species present												
Hilsa kelee	23	1		6	4	8	14		200		1	257
Thryssa vitrirostris	40	79	60		17					6	34	236
Leiognathus equula	14	56	100	1	19	3	14					207
Caranx sem	6	1	6	2								15
Scomberoides tol	5						1					6
Johnius dussumieri									1		1	2
Glossogobius callidus	1											1
Ambassis sp.	1											1
Arothron hispidus	1											1
Oreochromis mossambicus											1	1
Solea bleekeri											1	1
Strongylura leiura											1	1
Hemiramphus far											1	1
Not specified								40				40
Total	91	137	166	9	40	11	29	40	201	6	40	770
Fish per m	4,6	1,4	16,6	0,1	0,8	0,2	1,5	0,4	0,5	0,3	0,2	0,7

TABLE 3

NEST, EGG AND CHICK COUNTS MADE DURING VISITS TO CASPIAN TERN COLONIES AT LAKE ST LUCIA DURING 1987. (* = COURTSHIP OBSERVED; N/D = NO DATA; N/C = NO COUNT; ? = UNKNOWN)

Date	28 May	1 Jun	14 Jun	18 Jul	1 Aug	18 Aug	21 Aug	8 Sep	13 Sep	28 Sep
Lane Island										
Adults	46	37	129	102	29	17	88*	53	46	0
Clutches	1	3	42	66	6	6	N/C	1	0	0
Eggs	2	4	63	95	10	8	?	1	0	0
Chicks (new)	0	0	0	24	3	0	1	0	0	0
Bird Island										
Adults	N/D	N/D	223	91	26	27	N/D	86	N/D	0
Clutches	?	?	16	63	2	0	?	0	?	0
Eggs	?	?	23	102	3	0	?	0	?	0
Chicks (new)	?	?	0	11	4	0	?	0	?	0

During a reported die-off of Tilapia *Oreochromis mossambicus* in the freshwater Lake Bangazi-South, adjacent to Lake St Lucia at Cape Vidal in 1978 (Bruton & Taylor 1979), no water temperature data were available. However, it was reported that the lowest ambient temperature recorded at Charters Creek over that period was 3.8°C and that this was the second lowest temperature recorded in the area over the preceding 10 years. The minimum temperature recorded during the 1987 cold snap was of the same order, being 3.2°C (Table 1).

Fish kills at St Lucia have been reported on two previous occasions. In May 1976 a mass mortality of several species was recorded (Blaber & Whitfield 1976), and in March 1978 a mass mortality of the freshwater *O. mossambicus* occurred in the northern parts of the lake (Joubert 1978). This latter mortality was attributed to a lethal combination of low temperature and low salinity, which lead to osmoregulatory failure, or, if the fish survived those conditions, to fungal infection of skin lesions. The species most commonly recorded in the former die-off were *Argyrosomus hololepidotus, Caranx ignobilis, Johnius dussumieri, Hilsa kelee, Leiognathus equula, Pomadasys commersonni* and *Terapon jarbua.*

A major feature of the 1987 cold spell was that temperatures were consistently low for at least four to five days. In addition certain combinations of temperature and salinity are known to limit the distribution of a number of fish species inhabiting estuaries, as has for example been shown for *Ambassis* species which occur in South African systems (Martin 1988). During the 1987 cold spell, water temperatures were calculated to have been dropped to at least 14.0°C, while salinities in the lake ranged from 29 to 33‰. Such combinations were found by Martin (1988) to cause between 50 and 100% mortality in two of the estuarine associated *Ambassis* species he studied.

In addition the three fish species most affected by the June 1987 fish kill (*H. kelee, T. vitrirostris* and *L. equula*) are all tropical and subtropical species which are not recorded in the more temperate estuaries of the extreme south eastern and southern parts of South Africa. Also of significance is the fact that many of the temperate fish species which extend as far north as Lake St Lucia were not recorded dying in this particular fish kill. This may be related to the fact that water temperatures of around 14.0°C are regularly recorded in warm temperate southern African estuaries during winter and that those fish species are adapted to withstand such temperatures.

It can thus be concluded that the prime cause of the 1987 fish kill was a combination of temperature and lake salinity. Why the smaller species dominated the kill is more difficult to deduce, but may be due to the larger species having a wider salinity tolerance range. Those involved in the fish kill which occurred during May 1976 (Blaber & Whitfield 1976) were mostly the larger species which inhabit estuaries. These die-offs were also due to a lethal combination of temperature and salinity. However, both were at the low end of the scale (12°C and 1.0 to 3.5‰).

Relationship between the cold spell, fish kill and tern breeding

It appears that the cold snap had a direct effect on the eggs in the tern colony at the time it occurred, in that the decrease in temperature may have resulted in failure of the embryos to complete development. The result being that only 35 chicks hatched and survived from the 86 eggs present on 14 June.

By the end of the cold snap around 24 June (Table 1) NPB staff on the lake reported that no Caspian Terns were found foraging in the St Lucia System. Instead, NPB staff travelling up the beach observed numerous birds fishing out at sea, in the area immediately behind the wave formation zone, from St Lucia Estuary northwards to about 27 53S

(Fig. 1), indicating that the fish die-off had affected food availability in the lake. One of the species most affected, *T. vitrirostris* (Table 2), forms a major part of the diet of Caspian Terns at Lake St Lucia (pers. obs.). The major fish species in their diet are all essentially estuarine inhabitants, indicating that the birds foraging at sea were forced to hunt for species not normally taken, particularly during the breeding season when birds are closely tied to the lake system.

The relaying which occurred some 14 days after the initial failure of the colony produced 197 eggs some 97% of which were subsequently abandoned. Lack of food in the lake, and possibly a forced change of diet as a result of the cold snap, contributed to the majority of the second clutches, which should have hatched by 1 August (Table 3), being abandoned. The fact that almost the entire adult tern population moved away from the lake to forage at sea well into August, clearly indicates that the fish kill played the major role. The Caspian Terns were obviously able to obtain sufficient food from this source to produce replacement clutches immediately after the failure of the first. However, they appeared unable to obtain sufficient food to keep the breeding attempt going and a mass desertion of the colony took place. Unfortunately no data exists to indicate whether other bird or animal species were affected by the die-off.

By 4 July some of the terns had returned to forage on the lake, presumably concentrating on their other favoured prey, *Johnius dussumieri* (Whitfield & Blaber 1978), which appeared to have been little affected by the cold snap (Table 2). However, the bulk of the tern population was still hunting at sea and this continued for nearly two months after the cold snap.

The terns made their third breeding attempt of 1987, in September (Table 3), at a time when the juvenile fish, including *J. dussumieri*, that recruited into the estuary from the sea during late winter, had reached a suitable size to be preyed upon. The return also coincided with the time at which reproductively active *T. vitrirostris* reach peak numbers during their migration into St Lucia to spawn (Blaber 1979). This third breeding attempt by the terns also failed, due to heavy rains falling in the catchment, resulting in the breeding grounds being flooded.

The reason as to why the terns were not able to switch to feeding on *J. dussumieri* after a large proportion of the *T. vitrirostris* population had died may simply be due to the size class of the former species present in the system at the time being mostly too large for the terns or for feeding chicks. Whitfield & Blaber (1978) recorded that some 48% of the prey items taken by Caspian Terns at Lake St Lucia were in the mass class 11 to 30 g. Most *J. dussumieri* which recruited into the system during the previous winter would probably be larger than that at the time of the fish kill some 12 months later, thus limiting prey availability even further.

Implications of such an episodic event

The direct effects of the cold snap were clearly evident with the fish kill being of short-term duration. However, the indirect effects which have long-term implications were at first not evident and would not have been noticed for a number of years had it not been for the fact that a study of the breeding success of the Caspian Terns was underway at the time.

Since the start of the project in 1987 the breeding success of the Lake St Lucia population has been affected by low temperatures (this paper), floods, military activities and hippos (D.P. Cyrus unpubl. data). As a result only two successful breeding seasons have occurred over the past seven years. These were during 1990 and 1993 when 0.88 and 1.10 chicks were reared per pair (D.P. Cyrus unpubl. data). These figures are similar to those obtained from other colonies in South Africa by Hockey & Hockey (1980) who recorded 1.10 chicks per pair on the Berg River, southwestern

Cape, and Martin & Randall (1987) who recorded 1.24 and 0.80 at the Swartkops Estuary in the eastern Cape. The 1987 breeding attempt produced 42 chicks from a total of 327 eggs laid by 129 pairs, a rate equivalent to only 0,33 chicks per pair.

The long-term implications of the 1987 breeding failure where that recruitment into the population must have been reduced due to the low reproductive output. Such an impact would only have become evident some three to four years later (1989/90), when the birds first attain sexual maturity and rejoin the colony as active breeders. It has not been possible to ascertain if the failure of the 1987 breeding attempt has had a negative effect on the population because a number of other factors has led to the breeding colonies being disturbed over the intervening years (D.P. Cyrus unpubl. data). However, despite the fact that the number of pairs present has fluctuated widely over the past seven breeding attempts (range 119 to 210, mean 150 pairs), those of 1989 and 1990 comprised the smallest number of pairs recorded during the study to date. This could well be an indication that the population has decreased as a result of limited recruitment during 1987 when the cold spell occurred.

Results from the present study have shown that substantial and rapid decreases in water temperature have direct and indirect effects on the fauna of estuaries and that these may have either short- or long-term effects depending on what components of the ecosystem are affected. As with the first paper in this series (Cyrus 1988) the present work has highlighted the importance of establishing monitoring programmes which can be implemented immediately after an episodic event has occurred, so that the resulting effects, both short- and long-term, on the fauna may be more clearly understood.

ACKNOWLEDGEMENTS

We thank the University of Zululand Research Committee for assisting with the funding of this project, the Natal Parks Board for logistical support and assistance with the fish kill counts, John Travis, Rose Cyrus and Helga McLean for assistance in the field, Iain Bickerton for making his water temperature data from Charters Creek available, and Alan Whitfield and Paul Martin for comments on a draft of this paper. The sponsorship of the CRUZ research boat by SASOL is also gratefully acknowledged. The Caspian Tern project is ongoing and forms part of the Estuaries Special Programme (Natal Section) funded as a Joint Venture through the Foundation for Research Development.

REFERENCES

BEGG, G. 1978. The estuaries of Natal. *Natal Town Regional Planning Rpt* 41: 1-657.

BICKERTON, I.B. 1989. Aspects of the biology of the Genus *Macrobrachium* (Decapoda : Caridea : Palaemonidae) in the St Lucia System. *CSIR Res. Rpt* 684: 1-199.

BLABER, S.J.M. 1979. The biology of filter feeding teleosts in Lake St Lucia, Zululand. *J. Fish Biol.* 15: 37-59.

BLABER, S.J.M. & WHITFIELD, A.K. 1976. Large scale mortality of fish at St Lucia. *S. Afr. J. Sci.* 72: 218.

BRUTON, M.N. & TAYLOR, R.H. 1979. Cichlid fish mortality in a freshwater lake in Natal. *Lammergeyer* 27: 1-4.

COOPER, J., BROOKE, R.K., CYRUS, D.P., MARTIN, A.P., TAYLOR, R.H. & WILLIAMS, A.J. 1992. Distribution, population size and conservation of the Caspian Tern *Sterna caspia* in southern Africa. *Ostrich* 63: 58-67.

CYRUS, D.P. 1988. Episodic events and estuaries: effects of cyclonic flushing on the benthic fauna and diet of *Solea bleekeri* (Teleostei) in Lake St Lucia on the south-east coast of Africa. *J. Fish Biol.* 33 (Suppl. A): 1-7.

FORBES, A.T. & CYRUS, D.P. 1992. The impact of a major cyclone on a south-east African estuarine lake system. *Neth. J. Sea Res.* 30: 265-272.

HOCKEY, P.A.R. & HOCKEY, C.T. 1980. Notes on the Caspian Terns *Sterna caspia* breeding near the Berg River, southwestern Cape. *Cormorant* 8: 7-10.

JOUBERT, F. 1978. Fish mortality, St Lucia. Natal Parks Board Internal Report April 1978. 2 pp.

MACLEAN, G.L. 1985. Roberts' birds of southern Africa. Cape Town: John Voelcker Bird Book Fund.

MARTIN, A.P. & RANDALL, R.M. 1987. Numbers of waterbirds at a commercial saltpan, and suggestions for management. *S. Afr. J. Wildl. Res.* 17: 75-81.

MARTIN, T.J. 1988. Interaction of salinity and temperature as a mechanism for spatial separation of three co-existing species of Ambassidae (Cuvier) (Teleostei) in estuaries on the south-east coast of Africa. *J. Fish Biol.* 33 (Suppl. A): 9-15.

MARTIN, T.J., CYRUS, D.P. & FORBES, A.T. 1992. Episodic events: the effects of cyclonic flushing on the ichthyoplankton of St Lucia Estuary on the south-east coast of Africa. *Neth. J. Sea Res.* 30: 273-278.

WHITFIELD, A.K. & BLABER, S.J.M. 1978. Feeding ecology of piscivorous birds at Lake St Lucia. Part 1: diving birds. *Ostrich* 49: 185-198.

APPENDIX A

LIST OF SPECIES AFFECTED BY THE COLD SNAP OF 1987 (SIZE IN MM STANDARD LENGTH; SD = STANDARD DEVIATION)

Species	Size/Range	mean SD	Sample size
Ambassis spp.	45	-	1
Arothron hispidus	35	-	1
Caranx sem	120-350	171.4±74.5	7
Caranx sexfasciatus	195	-	1
Glossogobius callidus	95	-	1
Hemirhamphus far	195	-	1
Herklotsichthys quadrimaculatus	?	-	-
Hilsa kelee	65-255	185.4±40.1	23
Hippichthys spicifer	150	-	1
Johnius dussumieri	?	-	-
Leiognathus equula	75-165	139.6±22.6	13
Oreochromis mossambicus	?	-	-
Plectorhinchus gibbosus	370	-	1
Scomberoides tol	?	-	-
Solea bleekeri	?	-	-
Sphyraena jello?	?	-	-
Strongylura leiura	480	-	1
Terapon jarbua	28	-	1
Thryssa vitrirostris	50- 85	66.2± 9.9	40
Trichiurus lepturus	690	-	1
Valamugil cunnesius	290	-	1