



Are signals of prey variability present in the demographic characteristics of crested tern (*Sterna bergii*) populations in South Australia?

**Final Report to the South Australian Wildlife Conservation Fund
Project No 0256**

Authors: L.J. McLeay^{1,2,*}, B. Page¹, S.D. Goldsworthy¹ and T.M. Ward¹

¹ South Australian Research and Development Institute, Aquatic Sciences, 2 Hamra avenue West Beach. PO Box 120, Henley Beach, South Australia 5022, Australia.

² The University of Adelaide, School of Earth and Environmental Sciences, Adelaide, South Australia 5005, Australia.

Correspondence to L.J. McLeay: tel: +61 08 8207 5439; fax: +61 08 8207 5406; Email: mcleay.lachie@saugov.sa.gov.au

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Authors: L.J. McLeay, B. Page, S.D. Goldsworthy and T.M. Ward

Reviewers: Mr P. Rogers and Mr D. Hamer (SARDI Aquatic Sciences)

Approved by: Dr Marty Deveney (A/Program Leader, Marine Environment and Ecology)

Signed:

A handwritten signature in black ink, appearing to be 'Marty Deveney', written over a horizontal line.

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Executive Summary

This study augments previous research undertaken between 2004-2006 on the demographic characteristics and age-related morphology of crested terns (*Sterna bergii*) at Troubridge Island, Gulf St Vincent, South Australia. Previous research, which was partly funded by the Wildlife Conservation Fund (WCF), has now been accepted for publication in the ICES Journal of Marine Science and should be consulted for additional background information.

This report describes demographic and morphological information collected in the 2007/08 breeding season of crested terns on Troubridge Island, Gulf St Vincent, South Australia. Diet information is summarized for all data collected between 2003/04-2007/08.

The diet of crested tern chicks and adults between 2003 and 2007 contained varying proportions of seven fish species. Australian anchovy *Engraulis australis*, Australian sardine *Sardinops sagax*, blue sprat *Spratelloides robustus*, barracoutta *Thyrsites atun*, Degens leatherjacket *Thamnoconus degeni*, southern sea garfish *Hyporhamphus melanochir* and Australian herring *Arripis georgianus* were common in diets of adult crested terns and chicks, comprising > 15% of prey biomass in at least one stage of the breeding season in any year. Intrasession shifts in chick diet composition may be related to changes in the dietary requirements (size/shape) of chicks over the course of the provisioning period (McLeay unpublished data).

Crested terns breeding at Troubridge Island in 2007/08 were aged between 3 and 22 years. The proportion of different age classes in the colony indicated that recruitment is variable in this population. Adults aged 3, 6, 7, 12 and 22 years were present in lower proportions in the breeding colony compared to other cohorts. Absence of adults aged 3-7 years probably reflects the delayed recruitment to breeding. Adults aged 12 years were reared in 1995/96 when >70% of the sardine biomass was killed by herpesvirus (McLeay *et al.* in press). Cohorts aged 6 and 7 (reared in 2000/01, 2001/02) were also present in relatively low proportions in the breeding colony. Although these cohorts are not yet fully recruited to breeding, it is possible that the second mortality event, which finished in 1999, also had an impact on these cohorts. Future monitoring at Troubridge Island will enable any effects of this mortality event to be better understood. Adults from cohorts reared in years following the 1998/99 mortality event should be fully recruited to the breeding colony by the 2008/09 breeding season. Conversely, adults aged 8 years (reared in 1999/00), which were also reared immediately after sardine depletion by a second mortality event, were well represented in the breeding colony. This suggests this cohort was not affected by the sardine mortality event in 1998/99 and may reflect the ability of crested terns to buffer prey depletion events.

Females in cohorts reared < 1 year after the end of a sardine mortality event had significantly smaller morphology (culmen length, bill depth, head length) compared to females from other cohorts (ANOSIM, $R = 0.063$, $p = 0.045$). The difference in size between the two groups was largely explained by group differences in head length (SIMPER 49.1%) and culmen length (SIMPER 42.8%). The bill morphology of males did not differ significantly in size between treatment groups (ANOSIM $R = 0.02$, $p = 0.338$) however non-significant trends in bill morphology (culmen length and head length) were apparent for males reared in 1995 (aged 9 y) but not males reared in 1999 (aged 5 y).

Introduction

Survival and growth of seabirds has been shown to be influenced by food availability, which in turn may be influenced by environmental factors or fishing activities (Anderson *et al.*, 1980; Uttley *et al.*, 1989; Montevecchi 1993; Furness and Tasker, 2000; ICES, 2001). Recently the South Australian Sardine Fishery (SASF), which uses purse-seining methods to provide sardine *Sardinops sagax* to the Southern bluefin tuna *Thunnus maccoyii* mariculture industry in South Australia, has expanded in terms of catch, effort and investment. It is now Australia's largest fishery (by weight), with an annual catch in 2006 of ~ 25 000 t (Figure 1). The effects of "forage fish" overfishing on apex predators such as seabirds are well documented. For example, purse-seine fishing in Namibia and South Africa between 1956 and 1980 induced stock collapse of sardine and anchovy, causing populations of African penguin (*Spheniscus demersus*) and cape gannets (*Sula capensis*) to fall to almost one half (Burger and Cooper, 1984; Crawford and Dyer 1995; Crawford 1998). In response to the rapid growth of the SASF, and concerns about its potential ecological impacts, Australian fisheries managers are looking to incorporate reference points for sardine predators into management plans (Shanks, 2004).

In southern Australia in 1995 and 1998, 70% of the biomass of sardine was killed by herpesvirus (Gaughan *et al.*, 2000). Fish kills of this scale provide a unique opportunity to assess whether their effects are signaled in the diet, breeding, physiology or demography of top order predators such as crested terns. If so, they may provide useful information about the health of ecosystems and provide ecological reference points for use in fisheries management. Demographic data are a cost-effective and essential tool for monitoring the health of predator populations under different scenarios of environmental management but rely on large numbers of animals in the population being individually identified by tags or bands. Long term banding data are rare for seabirds and particularly rare for Australian seabird populations. The crested tern population on Troubridge Island in Gulf St Vincent is unique in the fact that over a third of the adults in the colony are banded. Approximately 1000 crested tern chicks per year have been banded by researchers on Troubridge Island since 1966 and the population now presents a unique opportunity to study demographic patterns of survival and growth.

This project followed up on previous research funded by the WCF in 2006/07. The objectives of the study were to:

1. Continue the demographic study of crested terns at Troubridge Island by deploying 1000 more bands on crested tern chicks, and capturing up to 600 banded known-age adults to enable a population age structure to be calculated.

2. Continue measuring the prey composition of crested terns to identify which prey are important components in the diet of chicks and adults, and
3. Continue monitoring the age-specific bill morphology of adult crested terns to assess whether crested terns reared in periods of low sardine availability had smaller morphology compared to other cohorts.

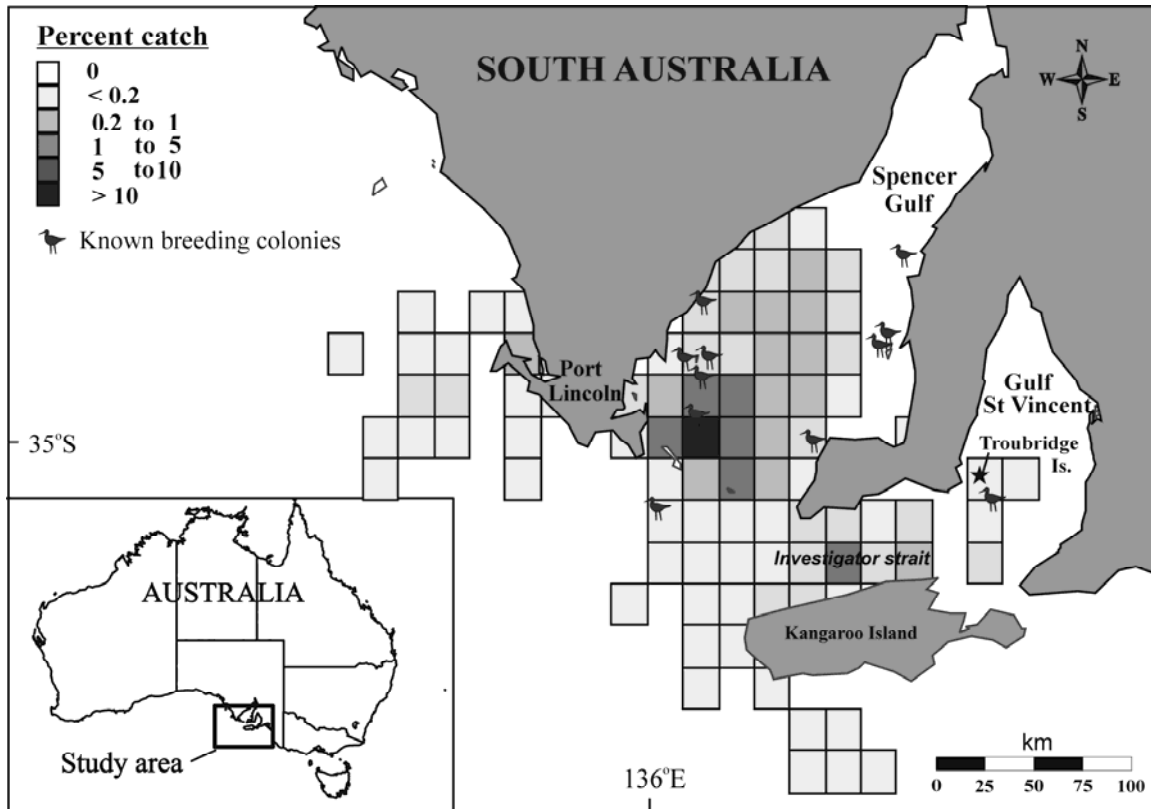


Figure 1. Location of Troubridge Island study site, crested tern breeding colonies and percentage catch of Australian sardine (*Sardinops sagax*) taken in South Australia by the SASF between 2001 and 2006. Inset shows study area.

Methods

Study site

This study was conducted at Troubridge Island in Gulf St Vincent, South Australia during the breeding seasons of crested terns between November and February in 2003/04, 2004/05, 2005/06, 2006/07 and 2007/08 (Figure 1). We refer to seasons or cohorts as belonging to the year that sampling or breeding began respectively (e.g. 1999/00 = 1999). The Troubridge Island colony is one of the largest in gulf waters of South Australia, with ~3500 pairs in 2005 (McLay unpublished data), and lies at the eastern extent of the region where the majority of the commercial catch is taken by the SASF (Figure 1).

Diet sampling

Regurgitates were collected crested tern chicks aged 0-5 weeks between 2003/04 and 2007/08 from. Regurgitates were collected from adults that were incubating eggs and provisioning chicks < 1 week old. Chicks and adults were caught by hand and hand-held nets respectively. To minimise disturbance to the colony during each visit, birds were caught by moving systematically from one end of the colony to the other. This also ensured no bird was caught more than once per visit. Samples, which were mainly undigested, were placed in a plastic bag and frozen before being sorted in the laboratory, where individual prey were separated and identified to the lowest taxonomic group possible. Species level identification of individuals from the families Clupeidae and Engraulidae was sometimes not possible. i.e. individuals may have been either one of these species. Hence, to determine the most important prey, we allocated unidentified individuals from these families proportionally to the groups identified specifically as sardine or Australian anchovy. The dietary composition of chicks and adults was analysed by percentage numerical abundance i.e the proportion of the total number of individual prey items made up by each prey taxon. To standardise for individuals that consumed more individual prey items, the average percent of each taxon was calculated over all regurgitates.

Age structure

Banding of crested tern chicks at Troubridge Island commenced in December 1966 (Waterman *et al.*, 2003). Since 1975, an average of 1348 chicks (s.e = ± 111.6 ; range 640 - 2350) have been banded annually, but no banding occurred between 1976 and 1985. The age distribution of the breeding adults in 2007 was determined by capturing adults on their nests with a hand-held net, recording band numbers, and referencing these against band records. The number of chicks banded each year was not the same so inter-annual differences in age structure were standardised by calculating the percentage of birds per cohort that were resighted.

Morphology

Adult birds with bands that were captured from their nests had the following morphological characters measured with vernier callipers (± 0.01 mm): Culmen length (*CL*): from base of forehead feathers to tip of bill; bill depth (*BD*): vertical thickness of the bill at the anterior edge of the nostrils; head length (*HIL*): distance from occiput to the tip of the bill. Birds were also weighed (± 5 g) before release and after any regurgitates were collected.

Age- and sex-specific differences in morphology

To test the hypothesis that smaller age-specific morphology (*CL*, *BD*, *HL*) was caused by a reduction in the abundance of sardines, we allocated individuals (pooled for three seasons 2004-2006) of each sex (Adults were sexed via discriminant function analyses) to a treatment group. (Mcley *et al.* in press).

Group 1: chicks hatched < 1 year after the end of each sardine mass-mortality event (i.e. the cohorts that were banded in December 1995 and 1999).

Group 2: chicks hatched in other years.

Treatment groups were assigned on the rationale that the timing of each sardine mortality event was different (March 1995 vs October 1998) and took four months to complete. Hence, the effects of decreased sardine abundance on crested terns were assumed to be most severe following the completion of a sardine mortality event and not while fish were still dying. Nonparametric analysis of similarity (ANOSIM) (for which R values are reported), on a Bray-Curtis similarity matrix (PRIMER version 5.1.2, PRIMER-E Ltd., Plymouth, UK) was used to test for significant differences in morphology between each treatment group for males (n = 652) and females (n = 575) ($p \leq 0.05$). ANOSIM tests the null hypothesis that within-group similarities do not exceed between group similarities. Similarity Percentages (SIMPER, Plymouth Routines in Multivariate Ecological Research) were used to determine which measure of morphology (*CL*, *BD*, *HL*) most contributed to the observed differences between treatment groups. Data from individuals caught and measured after the first recapture were excluded.

Results

Diet

The diet of crested tern chicks and adults between 2003 and 2007 contained varying proportions of seven fish species. Australian anchovy *Engraulis australis*, Australian sardine *Sardinops sagax*, blue sprat *Spratelloides robustus*, barracoutta *Thyrsites atun*, Degens leatherjacket *Thamnoconus degeni*, southern sea garfish *Hyporhamphus melanochir* and Australian herring *Arripis georgianus* were common in the diets of chicks and adults, comprising > 15% of prey biomass in at least one stage of the breeding season in any year. Intrasession shifts in chick diet composition may be related to changes in the dietary requirements (size/shape) of chicks over the course of the provisioning period (McLay unpublished data) (Table 1). Interannual differences in prey composition of chicks and adults suggest crested terns are able to switch prey and may be related to prey abundance or accessibility.

Table 1. Percent biomass contribution of prey taxa found in regurgitates from crested tern chicks and adults at Troubridge Island between 2003 and 2007. Taxa with biomass totals over 15% are in bold. Inc = Incubation period, E = early provisioning period, M = mid provisioning period, L = late provisioning period. The number of regurgitates examined is in brackets.

Prey type	2003	2004				2005						2006						2007						(2064)		
	(101) chick	(30) Inc adult	(76) E chick	(136) E adult	(139) Inc adult	(109) E chick	(71) E adult	(41) M chick	(16) M adult	(136) L chick	(4) L adult	(27) Inc adult	(75) E chick	(134) E adult	(39) M chick	(22) M adult	(67) L chick	(13) L adult	(235) Inc adult	(81) E chick	(99) E adult	(105) M chick	(95) M adult		(169) L chick	(44) L adult
Fish																										
Family Monacanthidae <i>T. degeni</i>	0.5	7.9		5.6	60.4	0.8	38.5		12.4	5.6		9.0	2.3	16.0	4.7	20.2	11.0	18.4	59.3	1.2	46.4	21.6	43.5	16.4	12.0	28.0
Family Clupeidae <i>S. sagax</i>	4.5	42.5	6.9	47.2	15.5	16.2	13.2	5.8	9.8	21.2		9.4	27.6	17.8	1.3	38.6	6.0	9.6	23.8	18.3	26.0	15.4	13.7	27.4	31.5	21.2
Family Gempylidae <i>T. atun</i>	31.9	22.8	27.9	24.1	0.5	3.7		63.5	42.1	19.4	7.0	50.3	27.2	48.8	54.0	24.9	25.3	27.3	0.4	7.8	2.7	4.2	0.7	1.6	5.2	16.0
Family Engraulidae <i>E. australis</i>	42.2	11.6	18.7	6.6	3.7	30.0	11.3	21.3	20.3	27.5		13.1	16.1	6.7	28.0	2.3	20.5	33.3	3.1	21.9	4.5	24.4	8.5	35.1	23.4	12.9
Family Hemiramphidae <i>H. melanochir</i>	6.2	9.2	3.7	7.0	6.8		28.5		2.9	10.0	59.1	11.8		1.3	1.8	12.3	7.9		3.8	1.1	6.1	2.7	3.8	5.3	3.3	6.1
Family Clupeidae <i>S. robustus</i>	4.5	0.6	33.6	4.9		7.2		1.0		0.4			8.1	0.4	1.0		0.7		1.1	35.3	1.3	16.2	0.4	6.3	0.5	3.5
Family Pempheridae <i>P. elongatus</i>	0.7		0.5		0.4	4.9	0.4		0.6			1.9	4.1	2.3	2.3		0.4		3.4	4.2	3.5	7.0	17.1	1.9	8.2	2.8
Class Actinopterygii- unidentified	1.5	2.3		1.6	4.0	16.3	1.8	5.1		1.5			4.2	3.6		1.7	2.7		0.8	3.5	0.9	0.6	0.5	1.0		2.1
Family Arripidae <i>A. georgianus</i>	1.1		0.9		2.8	15.6		1.2		1.7			4.8	0.5	1.7		0.9		0.2	4.7	0.3	1.9	0.8	1.7		1.4
Family Monacanthidae- unidentified	2.6			0.6	1.5	0.1	1.9		0.1	1.4	13.1	1.3		0.4			0.7	11.4	0.6	0.3	1.3	0.2	1.7	0.1	2.4	1.0
Family Odacidae- unidentified	1.6		3.0	0.9	0.2	1.4	0.2			4.6			0.9				2.5					3.2		1.3	8.1	1.0
Family Gonorynchidae <i>G. greyi</i>						0.2	0.1			0.1			0.4	0.1			0.2		0.3	0.4	2.0		0.4	0.4	0.9	0.3
Family Emmelichthyidae <i>E. nitidus nitidus</i>							1.3		4.6	2.4																0.3
Family Scorpaenidae- unidentified	0.9		0.9							0.4				0.5	1.7		0.9		0.3		0.4		0.8			0.3
Family Scombridae <i>S. australasicus</i>												1.3							0.3		0.6		0.2		2.3	0.2
Family Monacanthidae <i>Acanthaluteres</i> sp.				0.2	0.4	0.3	0.6			0.4													1.0			0.2
Family Clupeidae <i>E. teres</i>	0.3																		1.2							0.2
Family Sillaginidae <i>S. bassensis</i>					0.8																		2.6			0.2
Family Callorhinchidae <i>C. milii</i>														0.4										0.5	1.3	0.1
Family Atherinidae- unidentified													0.2							0.8			1.5	0.1		0.1
Family Diodontidae <i>D. nichthemerus</i>			2.4	0.3		0.5					20.8															0.1
Family Carangidae- <i>Pseudocaranx</i> sp		2.0							2.7																	0.1
Family Carangidae- <i>P. wrighti</i>	1.4				0.4	1.1		1.9																		0.1
Family Monacanthidae <i>S. granulatus</i>				0.4					3.7										0.2				0.6			0.1
Family Gerreidae <i>P. melbournensis</i>			0.8											0.2			0.7		0.1							0.1
Family Carangidae <i>Trachurus</i> sp.														0.4									1.2			0.1
Family Terapontidae <i>P. octolineatus</i>							0.6			0.5							1.1					0.9				0.1
Family Apogonidae <i>Vincentia</i> sp.				0.6	0.1																			0.2		0.1
Family Odacidae- <i>H. semifasciata</i>																							0.3			< 0.1
Family Gobiesocidae <i>Alabes</i> sp.																			0.2			0.6	0.0	0.0	0.0	< 0.1
Family Apogonidae- unidentified																			0.2							< 0.1
Family Syngnathidae <i>H. rostratus</i>								0.2																		< 0.1
Family Mugilidae <i>A. forsteri</i>										0.5							0.9									< 0.1
Family Labridae <i>N. balteatus</i>										0.5																< 0.1
Family Odacidae- unidentified													0.7													< 0.1
Family Clinidae- <i>Ophiclinus</i> sp.																										< 0.1
Family Mullidae <i>U. vlamingii</i>																	1.6									< 0.1
Family Syngnathidae <i>Hippocampus</i> sp.									0.1																	< 0.1
Family Apogonidae <i>S. cephalotes</i>																										< 0.1
Family Notocheiridae <i>I. rhothophilus</i>						1.7																				< 0.1
Family Monacanthidae <i>B. jacksonianus</i>	0.1																									< 0.1
Family Syngnathidae- unidentified																										< 0.1
Family Tetraodontidae- unidentified				0.7																				0.3		< 0.1
Family Tetraodontidae <i>C. richei</i>																			0.2			0.5				< 0.1
Cephalopods																										
Class Cephalopoda <i>N. gouldi</i>							0.1			0.5							14.2			0.5						0.5
Class Cephalopoda <i>S. australis</i>					0.5					0.9		0.8		0.6							3.2	0.6	0.2			0.3
Class Cephalopoda- unidentified					0.3		0.5			0.4									0.2		0.8		0.5			0.2
Family Sepiidae <i>E. tasmanica</i>														3.5			0.9									< 0.1
Family Sepiidae <i>S. apama</i>																								0.4		< 0.1
Crustaceans																										
Order Decapoda <i>M. latisulcatus</i>		1.0			0.5							1.1							0.3						0.8	0.1
Order Isopoda- unidentified							0.2																			< 0.1
Family Decapoda- unidentified																										< 0.1
Insects																										
Class Insecta- unidentified		0.1			1.2		0.8		0.7																	0.1
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Age structure

Crested terns breeding at Troubridge Island in 2007/08 were aged between 3 and 22 years (Figure 2). The proportion of different age classes in the colony indicated that recruitment is variable in this population. Adults aged 3, 6, 7, 12 and 22 years were present in lower proportions in the breeding colony compared to other cohorts. Absence of adults aged 3-7 years likely reflects the delayed breeding by adult crested terns. Adults aged 12 years were reared in 1995/96 when >70% of sardine biomass was killed by herpesvirus (McLeay *et al.* in press). Adults aged 6 and 7 (reared in 2000/01, 2001/02) were also present in relatively low proportions in the breeding colony. Although these cohorts are not yet fully recruited to breeding, it is possible that the second mortality event, which finished in 1999, also had an impact on these cohorts. Conversely, adults aged 8 years, which were also reared immediately after a second sardine mortality event, were well represented in the breeding colony.

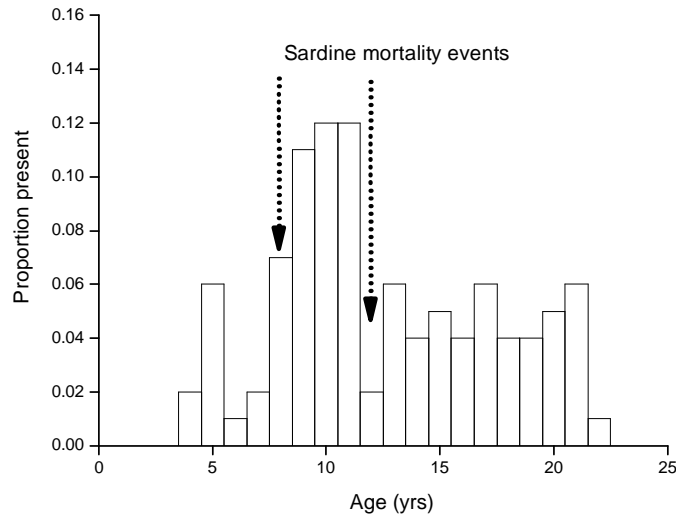


Figure 2. Age structure of crested terns breeding at Troubridge Island in 2008. Arrows show cohorts reared in years immediately following the completion of each Australian sardine mortality event.

Morphology

Females in cohorts reared < 1 year after the end of a sardine mortality event had significantly smaller morphology (culmen length, bill depth and head length) compared to females from other cohorts (ANOSIM $R = 0.063$, $p = 0.045$). The size of females differed between the two groups mainly due to differences in head length (SIMPER 49.1%) and culmen length (SIMPER 42.8%). The bill morphology of males did not differ significantly in size between treatment groups (ANOSIM $R = 0.02$, $p = 0.338$) however non-significant trends in bill morphology (culmen length and head length) were apparent for males reared in 1995 (aged 9 y) but not males reared in 1999 (aged 5 y) (Figure 3).

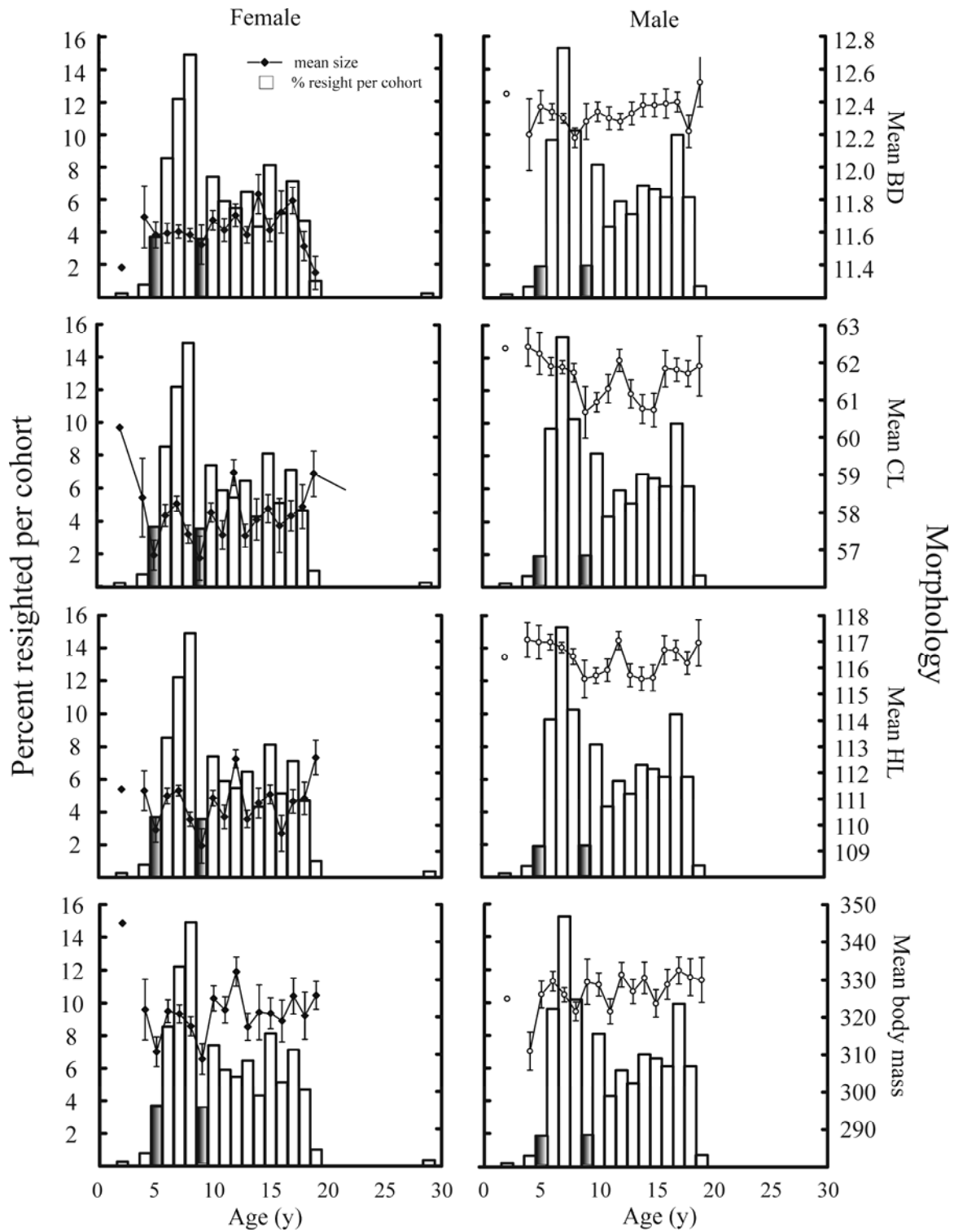


Figure 3. Trends in age structure (years) and mean morphology (BD, CL, HL (mm), body mass (g) (\pm s.e.), for breeding male and female crested terns at Troubridge Island (data pooled and ages corrected for individuals alive as of December 2004). Shaded bars represent cohorts reared <1 y after the completion of each sardine mortality event.

Discussion

One of the main concerns in modern fisheries management and marine conservation is the threat of stock collapse to apex predators. Age-specific information is often lacking in seabird studies because of the logistical constraints associated with banding many individuals over long periods of time. Moreover, inferences about foraging or breeding responses are made difficult by a lack of information about prey distribution and abundance. The crested tern colony at Troubridge Island in Gulf St Vincent is unique internationally as over a quarter of the adults are of known age and it is one of the longest “tagged” populations in Australia. This demographic information is vital to the understanding of population processes and long term responses of populations to changes in prey availability and/or environmental conditions. Current fishery monitoring includes biennial estimates of sardine spawning biomass. An ecosystem-based approach to management of marine resources will be significantly enhanced by coupling such estimates of prey biomass with demographic information from apex predators such as crested terns. Moreover, the value of such long-term datasets is enhanced over time. It is vital that monitoring of the demographic characteristics of the crested tern population at Troubridge Island continues, especially given the expansion of the South Australian Sardine Fishery and the potential impacts on key prey species such as sardine and other small pelagic fish species.

Age structure information indicated that crested terns reared after the first sardine mortality event in 1995 exhibited significantly lower rates of recruitment to the breeding colony compared to other age classes. Also, females from cohorts reared in 1995 and 1999, < 1 year following both sardine mortality events, had smaller morphology compared to other age classes. Crested terns reared in 1999 were well represented in the colony in 2007. This result was unexpected given the negative response of the 1995 cohort to the first sardine mortality event. Nonetheless individuals from the 2000 and 2001 cohorts (aged 6 and 7y) were not well represented in the colony. It is possible these cohorts may have been affected by the second mortality event in 1998 but they had not fully recruited to breeding age at the time of sampling in 2007. Monitoring in 2008/09 may better highlight any negative impacts caused by the sardine mortality event in 1998.

The importance of sardine (15 - 47 %) in the diet of crested terns supports the inference that prey absence caused by mass mortality of sardine was responsible for these negative effects and suggests crested terns may be sensitive to large scale decreases in sardine abundance. The presence of different proportions of these taxa in crested tern diets suggest they may be able to switch to alternate prey in periods of low sardine abundance however the SASF is licensed to take other small pelagic species such as anchovy and blue sprat. Harvest rates for these species are currently unquantified but may be significant. Moreover, other physical factors may affect breeding success. Hence more monitoring is

required to understand how breeding success of crested terns is affected by fishing, physical factors and the availability of key prey species within the foraging range of these apex predators.

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References

Anderson, D.W., Gress, F., Mais, K.F., and Kelly, P.R. 1980. Brown pelicans as anchovy stock indicators and their relationships to commercial fishing. CalCOFI Report 21: 54-61

Burger, A.E., and Cooper, J. 1984. The effects of fisheries on seabirds in South Africa and Namibia, *In* Marine birds: their feeding ecology and commercial fisheries relationships, pp 150-162. Ed. by D.N. Nettleship, G.A. Sanger and P.F. Springer. 220pp.

Crawford, R.J.M., and Dyer, B.M. 1995. Responses of four seabirds to a fluctuating availability of Cape Anchovy *Engraulis capensis* off South Africa. *Ibis*, 137: 329-339.

Crawford, R.J.M. 1998. Responses of African penguin to regime changes of sardine and anchovy in the Benguela system. *South African Journal of Marine Science*, 10: 365-381.

Furness, R.W., and Tasker, M.L. 2000. Seabird fishery interactions: quantifying the sensitivity of seabirds to reductions in sandeel abundance, and identification of key areas for sensitive seabirds in the North Sea. *Marine Ecology Progress Series*, 202: 253-264.

Gaughan, D.J., Mitchell, R.W., and Blight, S.J. 2000. Impact of mortality, possibly due to herpes virus, on pilchard *Sardinops sagax* stocks along the south west coast of Western Australia in 1998-99. *Marine and Freshwater Research*, 51: 601-612.

McLeay, L.J., Page, B., Goldsworthy, S. D., Ward, T.M., Paton, D.C., Waterman M. and Murray, M.D. (in press) Demographic and morphological responses to prey depletion in a crested tern *Sterna bergii* population: Can fish mortality events highlight performance indicators for fisheries management? *ICES Journal of Marine science*.

Montevecchi, W.A. 1993. Birds as indicators of change in marine prey stocks. *In* Birds as monitors of environmental change, pp. 217-266. Ed. by R.W Furness and J.J.D. Greenwood. Chapman and Hall, London. 356 pp.

Shanks, S. 2004. Ecological assessment of the South Australian Pilchard Fishery. Assessment report prepared for the ecologically sustainable management of fisheries. For the purposes of Part 13 and 13(A) of the Environment Protection and Biodiversity Conservation Act 1999. PIRSA, Adelaide. 51 pp.

Uttley, J., Monaghan, P., and White, S. 1989. Differential effects of reduced sandeel availability on two sympatrically breeding species of tern. *Ornis Scandinavica*, 20: 273-277.