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FORAGING RANGE, MARINE HABITAT AND DIET OF BRIDLED TERNS BREEDING IN WESTERN AUSTRALIA

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Bridled Terns breeding in Western Australia foraged over mid and outer continental shelf waters within about 70 km of their colonies. The diet of birds breeding on Penguin Island in south-western Australia consisted of a variety of small marine organisms including fishes, crustacea and cephalopods and also winged terrestrial insects. The most important marine prey were mullid (goatfish) larvae, shoaling clupeids and Columbus Crab megalopae.

The dietary information collected from this and other studies indicate that Bridled Terns forage over rafts of *Sargassum* and other flotsam particularly in the latter stages of the breeding season. This habit may distinguish the foraging ecology of Bridled Terns from that of other sympatric species. The availability of *Sargassum* rafts and flotsam in the marine environment may be a key factor influencing the Bridled Terns' breeding and wintering distribution.

INTRODUCTION

The Bridled Tern *Sterna anaethetus* breeds on about 150 continental islands in Western Australia between the latitudes 13° and 34° south (Johnstone *et al.*; in press, pers. obs.). The birds are present at their breeding stations and adjacent continental shelf waters from October to April (Dunlop and Jenkins 1992), with some minor regional and inter-annual variations. All the populations on the continental islands are migratory with birds from two south-western colonies known to winter in the north-western Celebes Sea (Dunlop and Johnstone 1994).

In the eastern Indian Ocean Bridled Terns are generally confined to outer continental shelf waters. By contrast the closely related Sooty Tern *Sterna fuscata*, which breeds sympatrically in some locations, has an oceanic distribution beyond the continental slope (Dunlop *et al.* 1988a). Bridled Terns range over water masses with higher sea-surface salinities and a greater range of temperatures than Sooty Terns. However, these oceanographic characteristics are correlated with shelf environments (Dunlop *et al.* 1988a) and may not be defining habitat variables.

The feeding method of Bridled Terns has been described as 'contact dipping' (Cramp 1985). When foraging, the bird hovers or glides close to the sea surface and only the head and breast are immersed in snatching the prey (Hulsman 1988; pers. obs). In order to be available the prey must be within a few centimetres of the surface (Cramp 1985; Hulsman 1988). Most tropical terns with a dark body or dorsum catch their food in this way and the Bridled Tern could be considered as part of this 'dark' tern guild.

Bridled Terns are known to take a range of small fishes, crustacea, cephalops and insects as prey. Dietary information based on regurgitations is available from colonies in the Seychelles (Diamond 1976) and from the Barrier Reef (Hulsman 1988). Other opportunistic records of prey items are summarized in Cramp (1985).

The purpose of this study was to investigate the feeding ecology of Bridled Terns breeding along the Western Australian coastline. The observations include dietary data from regurgitations collected at a study colony and records of Bridled Tern distribution and marine habitat at sea taken aboard the CSIRO Oceanographic Research Vessel RV Franklin.

METHODS

Diet study

The diet study was carried out on Penguin Island (32°17′S, 115°41′E) where Bridled Terns have been banded since 1983 (Dunlop and Jenkins 1992; Dunlop and Jenkins 1994).

During banding operations a variable proportion (5–40%) of the birds handled were observed to regurgitate prey. The variations probably related to differences in foraging conditions. Samples were most frequently available from terns captured at dusk or just after dark. Regurgitations occurred infrequently early in the season prior to hatching but later in the season adults, chicks and fledglings regurgitated relatively readily. Samples were collected during the 1994/95 and 1995/96 breeding seasons. Field visits occurred at approximately three week intervals from October to March.

Samples (N = 140 regurgitations from individual Bridled Terns) were preserved in 70 per cent ethanol and prey items sorted and identified. Some prey types, particularly small fishes, were heavily digested whilst others such as crab megalopae and insects were usually intact. Entire specimens of all taxa were preserved for identification and for the measurement of body proportions to assist in estimating the total length of fragmentary prey items in the samples. These specimens were added to a reference collection of identified tern prey types held by C. Surman at Murdoch University. This collection was utilized to confirm the identity of a number of juvenile and larval fish taxa. Specimens of fish and crustaceans were also identified or cross checked by taxonomists at the Western Australian Museum and fisheries biologists at the Western Australian Marine Research Laboratories.

Foraging distribution

Observations of Bridled Terns at sea were made between 21 and 30 March 1996 from the CSIRO Oceanographic Research Vessel RV Franklin. This cruise involved 12 east-west traverses across the continental shelf between Dampier on the north-western coast (20°25′S latitude) and Fremantle (32°00′S) in the south-west. Bridled Tern colonies are found along almost all of this stretch of coastline, with the only vacant area being between NorthWest Cape and Shark Bay. The survey coincided with the late fledging, pre-exodus period at most colonies (Dunlop and Jenkins 1992; Johnstone *et al.*, in press).

The methodology used in the RV Franklin seabird surveys has been described in some detail in Dunlop *et al.* 1988b. The Bridled Tern observations constitute daylight visual contacts from the vessel made during 30 minute periods whilst the vessel was steaming (average speed around 10 knots).

All seabirds were counted over the semi-circular field (radius 300 m) forward of the observer on the bridge. Each period therefore surveyed approximately 5.5 km^2 of ocean surface. Eighty-four 30 minute periods were completed during the cruise giving a total census area of 462 km^2. The location of each observation period was plotted on the marine chart and the minimum distance to the nearest known Bridled Tern breeding colony was measured.

Throughout the cruise Franklin's thermosalinograph monitored sea-surface temperatures and salinity at 4 m depth. These measurements together with water depth and the ship's position, determined using the satellite navigation system, were logged at the beginning and end of each 30 minute count. Current vectors were available throughout from the ship's acoustic Doppler current profiler. The position of the Leeuwin Current was inferred from the measurement of southerly current vectors, changes in sea-surface temperature and salinity and/or geographical position on the continental slope.

RESULTS

Diet study

The prey taxa identified from regurgitated food samples collected at the Penguin Island colony are summarized in Table 1. Twenty marine taxa were recorded, numerically the most important prey being small clupeids, larval Black-spot Goatfish *Parupeneus signatus* and Columbus Crab *Planes cyaneus* megalopae. Winged terrestrial insects were also frequently taken including Lepidoptera, Hymenoptera, Hemiptera and Coleoptera.

Figure 1 shows the percentage frequency at which the small Clupeidae, larval Mullidae (Goatfish), larval Gonorhynchidae (Beaked Salmon) and Columbus Crab megalopae occurred in monthly regurgitation samples collected in the 1994/95 and 1995/96 seasons.

The small clupeids were not present in the 1994/95 samples but were taken exclusively early in the 1995/96 breeding season. The mullid larvae were important prey items from December onwards in both years, replacing the small clupeids as the primary food source in the latter half of the 1995/96 season. More Gonorhynchid larvae were recorded in 1994/95 than in 1995/96, when they were only present in the December samples.

The megalopae of the Colombus Crab appeared in the food samples towards the end of the season in both years (Fig. 1).

Bridled Terns took prey with measured or estimated total lengths from 4 to 100 mm. Amongst the fish prey, larval mullids were usually heavily digested. As most intact mullid specimens were between 20 and 40 mm it is probable that the number of individuals taken across these classes was underestimated. The small clupeids were relatively intact although frequently the

TABLE 1

Prey taken by Bridled Terns on Penguin Island (N = 140).

Prey taxa	No. of samples	No. of individuals
Fishes		
Clupeidae		
Hyperlophus vittatus	10	48
Sardinops neopilchardus	42	97
Spratelloides gracilis	1	9
Spratelloides robustus	4	7
Larval clupeid	1	1
Gonorhynchidae		
Gonorhynchus greyi (larval)	8	13
Hemirhamphidae		
Hyporhamphus sp. (juv.)	6	6
Syngnathidae		
Hippocampus sp. nov.	3	4
Apogonidae		
Apogon sp.	1	1
Carangidae		
Naucrates ductor (juv.)	3	6
Pseudocarnax sp. (juv.)	1	1
Pomotomodae		
Pomatomus saltator (juv.)	1	2
Mullidae		
Parupeneus signatus (larval)	44	92
Blennidae		
Petroscirtes breviceps (juv.)	1	1
Parablennius postoculomaculatus (juv.)	4	10
Monocanthidae		
Acanthaluteres sp. (juv.)	4	8
Tetraodontidae		
Lagocephalus sceleratus	2	2
Crustaceans		
Grapsidae		
Planes cyaneus (megalopae)	17	51
Dromidae		
Dromidia sp.	3	12
Cephalopods		
Unidentified squid	1	1
Terrestrial insects	19	227

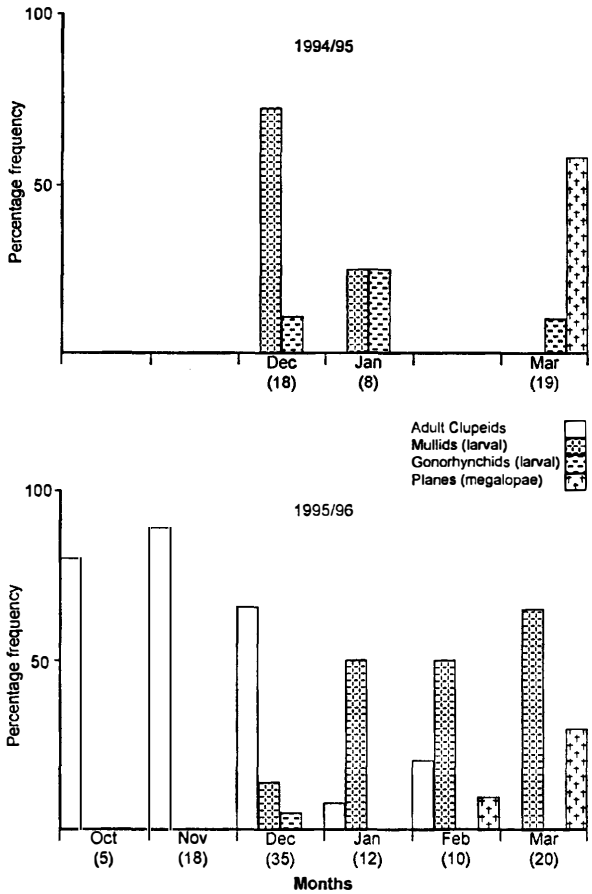

Figure 1. *Percentage of regurgitated prey samples containing adult Clupeids, larval Mullids, larval Gonorhynchids and/or* Planes megalopae *in monthly collections taken at the Penguin Island colony during the 1994/95 and 1995/96 breeding seasons. The number of samples per month are shown in parentheses.*

heads were detached at the gill arch. The larval crabs and insects were relatively undigested and frequently represented by whole specimens.

Figure 2 shows the percentage frequency distribution of prey lengths in 10 mm classes. The largest proportion of prey items were less than 10 mm in length. This length class included Columbus Crab megalopae, insects and a variety of larval fishes. A second mode between 20 and 40 mm consisted predominately of larval Goatfish. The third mode at 60 to 70 mm was made up largely of the small clupeids.

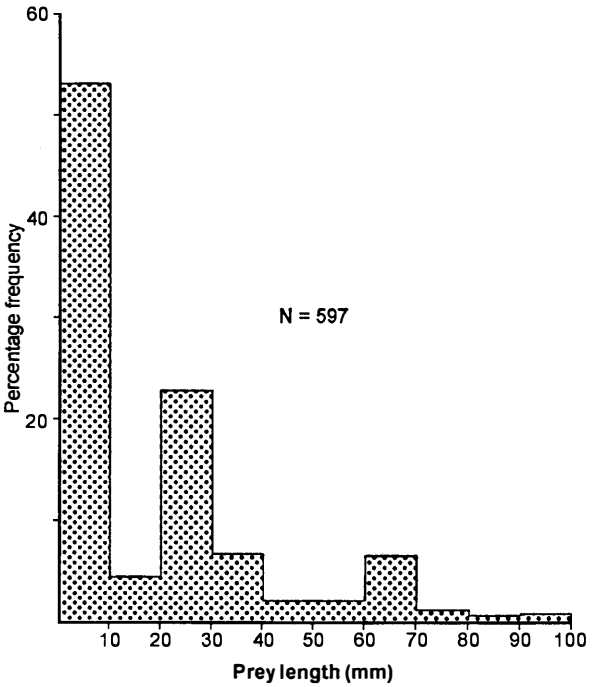

Figure 2. *The percentage frequency of Bridled Tern prey lengths in 10 mm classes. The sample size (N = 597) is the number of prey items.*

Foraging distribution

Bridled Terns were observed at sea on 28 (33.3%) of the 30 minute periods. Only five (3.6%) of the birds sighted were observed before 0900 hrs and all these birds were within 20 km of the nearest colony. The remaining 96.4 per cent of observations were between 0900 hrs and 1800 hrs. There were no significant differences between range classes in the time of day that birds were observed. The data from all count periods have therefore been combined.

Figure 3 shows the distribution of Bridled Terns in 20 km distance classes from the the nearest colonies. The number of terns observed per count peaked in the 20–40 km class. All the Bridled Terns observed at sea were within 71 km of a colony (Fig. 3), although the sampling ranged out to 297 km. Within the range over which Bridled Terns were observed, the distribution of birds differed significantly between the distance classes ($\chi^2 = 59.4$, df = 3, $P < 0.001$). Significantly more Bridled Terns were observed in the 20–40 km class ($\chi^2 = 34.0$, $p < 0.001$) and significantly less in the 60–80 km class ($\chi^2 = 23.05$, $p < 0.001$).

At this time in the annual cycle Bridled Terns were mainly confined to shelf waters and continental slope within 71 km of their colonies. These terns were observed foraging over the Leeuwin Current at the shelf break but most sightings were over shelf waters of higher salinity inside this water mass.

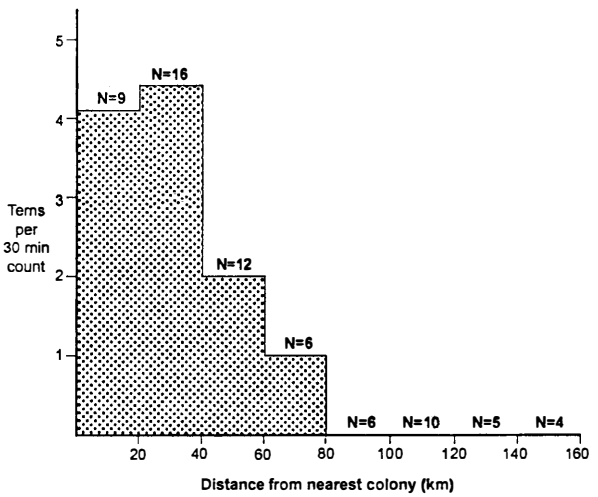

Figure 3. *The number of Bridled Terns observed per 30 minute count in 20 km distance classes from the nearest breeding island. The number of counts in each distance class is shown above each column.*

DISCUSSION

Bridled Terns breeding along the Western Australian coastline foraged over mid and outer shelf waters within about 70 km of the nearest breeding colonies. This foraging pattern contrasts with the closely related Sooty Tern in the eastern Indian Ocean which is pelagic and rarely observed feeding over the continental slope (Dunlop *et al.* 1988a; C. Surman, in prep.). There was no direct relationship between Bridled Tern foraging areas and the water masses of the Leeuwin Current at this time.

The diet study of Bridled Terns breeding on Penguin Island indicates that shoaling clupeid fishes, which are usually made available at the

surface by predatory fish (Hulsman 1988; pers. obs.), are taken at least in some seasons. Fisheries information suggests that for the two years studied the occurrence of clupeids in the samples was related to availability. Juvenile *Sardinops* and *Hyperlophus* were scarce in nearby coastal waters in 1994/95 and relatively abundant in 1995/96 Island (R. Fletcher, pers. comm.).

Bridled Terns take a wide range of other prey types. Some such as larval mullids and larval Gonorhynchids are also the mainstay prey of Common Noddies *Anous stolidus* and Lesser Noddies *Anous tenuirostris* breeding within the region at the Houtman Abrolhos (C. Surman, pers. comm.). In common with the Bridled Tern, these are tropical dark terns which take their prey close to the surface by 'contact dipping'. Both noddies also tend to feed offshore over outer shelf and shelf edge waters (C. Surman, pers. comm.).

Prey taxa including the Columbus Crabs *Planes cyaneus* (Butler *et al.* 1983; Jones and Morgan 1994), Sargassum Seahorses *Hippocampus* sp. nov. (Hutchins 1995, pers. comm.) and possibly the Sponge Crab *Dromidia* sp. (D. Jones, pers. comm.) are restricted to drifting rafts of *Sargassum* and other flotsam.

The *Sargassum* rafts also attract and shelter a variety of larval and juvenile fishes. Hutchins (1995) lists the 23 fish taxa most frequently found in association with the 'drift weed' around Rottnest Island. Seven of the 17 fish taxa recorded in the diet samples from Penguin Island were recorded on this list including *Parupeneus signatus* (larval), *Acanthaluteres* sp. (juvenile), *Parablennius postoculomaculatus* (juvenile), *Hippocampus* sp. nov., *Pseudocaranx* sp. (juvenile), *Petrascirtes breviceps* (juvenile) and *Hyporhampus melanochir* (juvenile). Other fishes taken by Bridled Terns such as juvenile Pilot Fish *Naucrates ductor* are known to accompany floating weed or jellyfish (Allen and Swainston 1988).

Clearly, the consistent presence of both obligate and facultative inhabitants of the floating *Sargassum* community in the diet of Bridled Terns suggests that foraging over drift weed rafts is a significant part of the feeding niche in this species. The obligate component of the Sargasso-fauna may be more available towards the end of the breeding season in February and March. The rafts are more extensive in late summer and early Autumn (Hansen 1984; Hutchins 1995) and this may coincide with a peak in dispersal and recruitment in the *Sargassum* community. The Leeuwin Current usually begins to flow strongly in March (Cresswell 1990) and may transport the larval stages of the tropical Sargasso-fauna into the shelf waters off south-western Australia at this time (Hutchins 1995).

The windrows of seaweed and other floating material are assembled by the wind driven Langmuir Circulation (Butler *et al.* 1983). This system of counter-rotating horizontal eddies, which concentrate floating material at the intervening down-welling zone, would not only gather marine life and flotsam but also terrestrial organisms which have settled on the ocean surface. Thus the winged terrestrial insects which appeared fairly frequently in the Bridled Tern diet samples may also be taken by birds working the *Sargassum* rafts.

Haney (1986) found that Bridled Terns foraged over the warm core filaments of Gulf Stream frontal eddies where large mats of *Sargassum* were entrained by down-welling or convergence. This authority also reports that off the south-eastern United States *S. anaethetus* forages primarily for fish associated with large mats of pelagic *Sargassum.*

A diet study of Bridled Terns breeding in the Seychelles (Diamond 1976) found that 89.8 per cent of the fish taken were mullids. This study also reports the presence of larval crabs, Hemiramphidae and Tetraodontidae. However, Hulsman (1988) records Balistidae (Triggerfishes) as the dominant fish prey from the Great Barrier Reef and did not identify any mullids.

The characteristics of Bridled Tern feeding ecology in Western Australian waters have much in common with those reported from the Gulf Stream region and the Seychelles, particularly in relation to the role of the Sargasso-fauna. The attachment of the species to shelf waters in Western Australia may be related to the continental edge availability of floating *Sargassum*, which is detached from reefs during the spring and summer (Hansen 1984). The wintering area in the Celebes Sea is also likely to be rich in *Sargassum* rafts and flotsam.

The frequency distribution of prey lengths taken by Bridled Terns almost certainly overestimated the proportion of items below 10 mm, as this class included most of the hard bodied prey

of crabs and insects. Nevertheless it is clear that Bridled Terns do take a significant proportion of small prey.

The mean and modal prey length taken by the slightly smaller Lesser Noddy is 30 mm and in the larger Common Noddy is 50 mm. In these species the distributions of prey taken are basically unimodal around the preferred prey length (C. Surman, pers. comm.). In the Bridled Tern the distribution of prey taken tends to be multimodal which reflects the much broader feeding niche of this species in comparison to the other tropical 'dark' terns.

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