EVIDENCE FOR NOCTURNAL INTER-TIDAL FORAGING BY EUROPEAN STORM-PETRELS *HYDROBATES PELAGICUS* DURING MIGRATION

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Thomas, R.J., Medeiros, R.J. & Pollard, A.L. 2006. Evidence for nocturnal inter-tidal foraging by European Storm-petrels *Hydrobates pelagicus* during migration. Atlantic Seabirds 8(1/2): 87-96. *European Storm-petrels* Hydrobates pelagicus *have previously been assumed to be exclusively pelagic foragers during migration. However, in this paper we report evidence that migrating Storm-petrels also forage at night along beaches. We highlight the repeated occurrence of the inter-tidal crustaceans* Eurydice naylori *&* E. affinis *(Isopoda: Cirolanidae) in the regurgitated crop contents of European Storm-petrels captured for ringing during their northwards migration past SW Portugal. The combination of the fresh condition of these crustaceans, their habitat and limited inter-tidal distribution and their nocturnal pattern of activity, together indicate that the Storm-petrels which had eaten them had been foraging by night along the inter-tidal zone of sandy beaches. We also found subtidal* Eurydice *species in the regurgitated samples, including the offshore species* E. inermis *and* E. truncata *that are nocturnal vertical migrants to the sea surface, providing further clues as to the location and timing of Storm-petrel foraging. We highlight the insights into the foraging behaviour of migrating Storm-petrels that can be obtained from the study of their gut contents and the behaviour and ecology of their prey.*

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INTRODUCTION

Very little is known about the diet of seabirds during their long-distance migrations because of the difficulty of observing or catching birds on passage and of obtaining food samples from them. The Atlantic population of the British or European Storm-petrel *Hydrobates pelagicus* (henceforth "Storm-petrel") migrates between its breeding colonies on islands and promontories in the NE Atlantic and its wintering grounds in South Atlantic waters off southern Africa (Wernham *et al.* 2002). As with most seabird research, all systematic studies of Storm-petrel foraging ecology have focussed on the breeding colonies, where birds are accessible to researchers (Scott 1970, Cramp & Simmons 1977, D'Elbée & Hémery 1998). However, work by A Rocha Bird Observatory in SW Portugal has shown that Storm-petrels can be attracted to nocturnal shoreline

tape-lures during their summer passage migration past the Portuguese coast, several hundred km from the nearest known breeding colonies. At this time, the birds are heading rapidly northwards, often at speeds of over 100km/day (Harris *et al.* 1993, Wernham *et al.* 2002, A Rocha Bird Observatory unpublished data). Mist-netting the birds attracted to these tape lures provides a valuable opportunity to study Storm-petrels during their long-distance migration. Most of the birds mist-netted in this way are thought to be wandering pre-breeders, in their second to fourth calendar years, which move into the NE Atlantic in mid-summer, prospecting for mates and future nest sites (Bolton & Thomas 2001, Wernham *et al.* 2002, Okill & Bolton 2005).

Storm-petrels are widely considered to be highly pelagic seabirds, and are generally thought to visit land only to breed, or when driven into inshore waters or even inland during storms (Cramp & Simmons 1977). During the season of northwards migration past Portugal (June), they are frequently observed during daylight by birdwatchers on pelagic boat trips several km off the southern Portuguese coast, with an apparent concentration of foraging birds seen at the edge of the continental shelf approx. 8-12 km offshore (pers. obs.), including in mixed species assemblages scavenging behind fishing boats (Valeiras 2003). Such observations, together with the lack of observations of Storm-petrels from shoreline vantage points have led to the assumption that Storm-petrels are exclusively pelagic foragers during migration.

A small proportion (<5%) of the Storm-petrels mist netted during migration past Portugal employ the anti-predator strategy of regurgitating a mixture of stomach oils and partly digested food from their proventriculus (crop), thereby providing a convenient opportunity to obtain information about the birds' diet during the migration journey. Visual identification of food items in Storm-petrel vomit samples is sometimes possible, though the vomit often contains prey material that is too well digested to be identified, or contains stomach oils only.

In this paper, we report evidence from a number of particularly revealing vomit samples, which suggest that Storm-petrels may forage at night along the intertidal zone of Portuguese sandy beaches during their northwards migration, rather than exclusively far offshore as has generally been assumed.

METHODS

We captured Storm-petrels in mist nets, to which they were attracted by playing tape-recordings of the species' "burrow call" (Cramp & Simmons 1977). These tape-lures were played throughout the night on a wave-cut platform at the base of a sea-cliff at Ponta da Almadena, on the south coast of the Algarve, Portugal (N 37° 04', W 8° 47'). We collected samples of regurgitated proventriculus/

stomach contents from the minority of birds which vomited during capture and handling. The regurgitated material was stored in 96% ethanol for subsequent identification and analysis.

Though the capture site is on a rocky shoreline, it is within approx. 1km of sandy beaches to the east and west. At the beach to the west of the capture site, we sampled potential Storm-petrel prey taxa in the surf zone at hourly intervals through the night, from 20:00 GMT (dusk) to 05:00 GMT (dawn), as well as additional samples during full daylight at approx. 06:00 GMT. We waded approx. 3m out from the shore into the surf (i.e. the exact position up the beach varying with the tide), and swept along a 1m line parallel with the shore, for 2 minutes using a long-handled hand net with 500µm mesh (Alana Ecology Ltd., Shropshire, UK). All live animals captured were fixed and stored in 96% ethanol, and were later visually identified to genus level (Jones & Pierpoint 1997).

To study the behaviour of stranded but living *Eurydice* isopods, we netted *Eurydice* individuals from the surf zone at night, and placed them immediately on damp sand just above the reach of the breaking waves, in order to observe their behaviour, including the time taken for them to bury themselves in the sand.

Tide times were calculated for Lagos, Portugal (10km east of the study site at 37.10°N, 8.67°W), using the Neptune Tides programme (v6.15, Neptune Navigation, Reading, UK).

RESULTS

Regurgitated samples We captured 116 and 436 Storm-petrels during late May–late June in 2004 and 2005 respectively. From these, we collected vomit samples from 32 birds. Eight of these 32 individuals regurgitated a total of 23 intact and apparently undigested small crustaceans of the Genus *Eurydice*. Figure 1 illustrates the intact nature of the specimens. The majority of the regurgitated specimens were subsequently identified to species level on the basis of skeletal morphology, by Prof. David Jones of Bangor University, UK (Jones & Pierpoint 1997). Table 1 shows the *Eurydice* species identified in each regurgitate sample, and the habitats of these species. The stage of the tidal cycle at which each *Eurydice* species was obtained in regurgitated samples is shown in Figure 2, and indicates that Storm-petrels forage on *Eurydice* throughout the tidal cycle. The graph also shows that the records of regurgitated isopods are clustered in the second half of the night, but this simply reflects the fact that the numbers of Storm-petrel arriving at the tape-lure peaks in the hours between 01:00 and 05:00 GMT (A Rocha Bird Observatory, unpublished data).

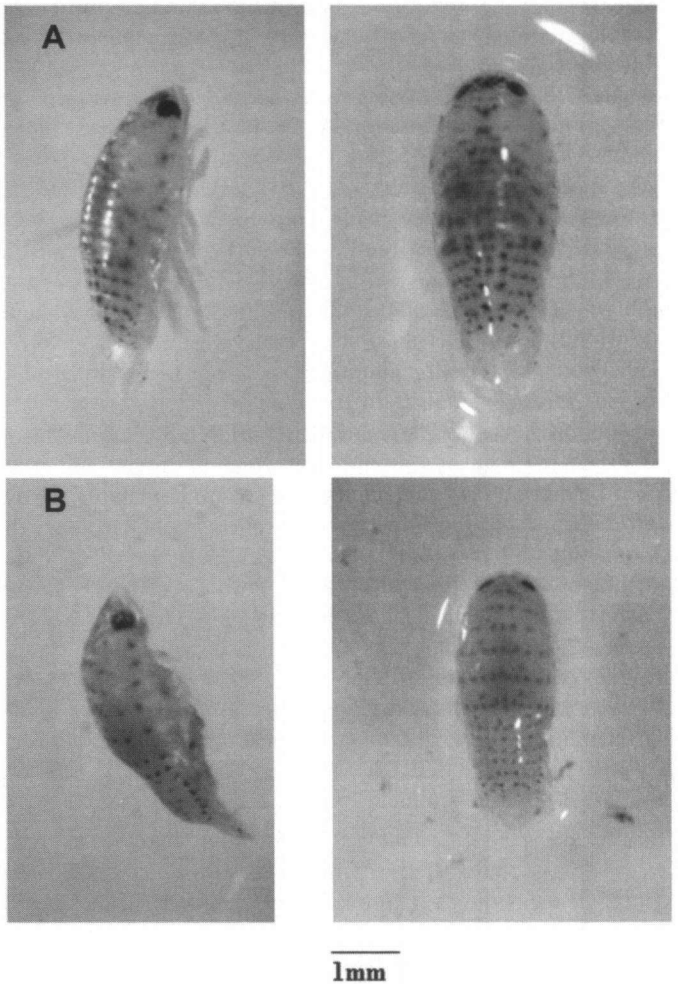

Figure 1: A) Fresh specimen of the intertidal isopod Eurydice affinis, *obtained by hand-netting in the surf zone of a Portuguese beach. B) Typical specimen of* Eurydice affinis, *obtained from the regurgitated stomach contents of Storm-petrels captured in Portugal during the June passage migration season. Photographs by Geoff Swann, Cardiff University.*

Figuur 1: A) 'Vers' exemlaar van de isopode Eurydice affinis *uit de, intergetijdenzone verzameld met behulp van een handnet in de branding van een Portugees strand. B) Karakteristiekexemplaar van* Eurydice affinis, *verkregen uit uitgebraakte maaginhouden van Stormvogeltjes die in juni in Portugal tijdens de trek zijn gevangen. Foto's Geoff Swann, Cardiff University.*

Table 1. Date and time of capture (GMT) of each Storm-petrel that regurgitated Eurydice *isopods. The habitat of each* Eurydice *species is indicated as follows: I = Intertidal, S = Subtidal, O = Offshore.*

Tabel 1. Datum en vangsttijd (GMT) van Stormvogeltjes die Eurydice*-isopoden opbraakten.. De habitat van de* Eurydice*-soorten is aangegeven met: I = Intergetijdezone, S = Sublitoraal, O = Offshore.*

Storm-petrel ring number	Night	Time of capture (GMT)	*Eurydice* species found in vomit sample	Habitat of *Eurydice* sp
N01950	7-8 June 04	00:10	4 x *Eurydice naylori*	I
N02370	2-3 June 05	01:18	1 x *Eurydice affinis*	I
			1 x *Eurydice truncata*	O
			1 x *Eurydice* sp.	-
N02379	2-3 June 05	01:59	4 x *Eurydice affinis*	I
N02386	2-3 June 05	02:20	2 x *Eurydice affinis*	I
			1 x *Eurydice truncata*	O
N02402	3-4 June 05	22:54	3 x *Eurydice spinigera*	S
N02547	5-6 June 05	02:28	1 x *Eurydice truncata*	O
			2 x *E inermis*	O
N02564	5-6 June 05	04:10	1 x *Eurydice affinis*	I
N03114	14-15 June 05	22:55	2 x *Eurydice* sp.	-

Many of the birds that we captured also regurgitated fish remains and clear "stomach oil", along with other more digested material that could not be identified visually.

Behaviour & availability of live *Eurydice* isopods and other potential prey

Our hand-net sampling revealed that *Eurydice* isopods were almost totally absent from samples taken from the surf zone during full daylight, but they appeared in the water column as dusk approached. They were abundant in the surf throughout the night, and disappeared (presumably into the sand) soon after dawn. Our visual searching during daylight to find *Eurydice* isopods proved that they are extremely difficult for humans to find in sand, even during daylight, because of their small size and cryptic colouration.

We found that *Eurydice* isopods placed on damp sand just above the tide level at night immediately began to bury themselves, and disappeared from view into the sand within 2 minutes.

We observed that Sandhoppers (Amphipoda: Orchestiidae) and the small crustacean *Gastrosaccus spinifer* (Mysidacea: Mysidae) were even more abundant than *Eurydice* isopods at night on the exposed sand and in the water column of the intertidal zone, respectively. However, despite their apparent availability, these potential prey taxa were strikingly absent from any of the identifiable prey remains in any of the Storm-petrel vomit samples.

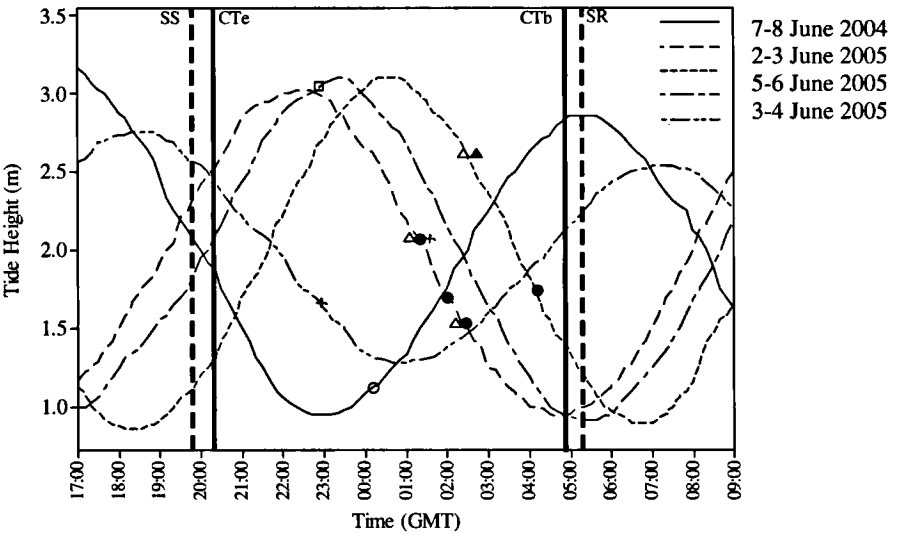

Figure 2. Tidal cycles on nights when mist-netted Storm-petrels regurgitated Eurydice isopods. SS = Sunset, SR = Sunrise, Cte = Civil twilight ends, CTb = Civil twilight begins. The following symbols indicate different species of isopod and their habitats: Intertidal species: ○ = E. naylori,● = E. affinis*; Subtidal species:* □ = E. spinigera*; Offshore species:* Δ = E. truncata, ▲ = E. inermis*; + = Unidentified* Eurydice *sp*

Figuur 2. Getijdencycli tijdens nachten dat gevangen Stormvogeltjes Eurydice *isopoden opbraakten. SS = zonsondergang, SR = zonsopkomst, Cte = begin schemering, CTb = einde schemering. Soorten van intergetijdezone:* ○ *= E. naylori,* ●*= E. affinis; Sublitorale soorten:* □ *= E. spinigera; Offshore soorten:* Δ*= E. truncata,* ▲*= E. inermis; + = Unidentified Eurydice sp*

DISCUSSION

We found a total of five *Eurydice* species in the gut contents regurgitated by mist-netted Storm-petrels (Table 1). Of these, two species have intertidal distributions (*E. naylori* & *E. affinis*), two are offshore species (*E. truncata* & *E. inermis*), and one species (*E. spinigera*) is largely subtidal but occurs in smaller numbers in the intertidal zone (Jones & Pierpoint 1997).

Eurydice naylori and *E. affinis* are restricted to the inter-tidal zone, with greatest concentrations in the upper half of the tidal range, i.e. the zone between Mean Tidal Level and High Water Neap Level (Jones & Pierpoint 1997). Thus, the occurrence of fresh specimens of these species in the vomit of five of the eight migrating Storm-petrels that regurgitated *Eurydice* isopods (Table 1) indicates that these individual birds had been foraging in the inter-tidal zone.

E. naylori and *E. affinis* are normally found in the top 10-15cm of sand, but at night they emerge into the water column of the surf zone as the tide comes in (Salvat 1966, Jones & Pierpoint 1997). Several pieces of evidence suggest that Storm-petrels obtain these intertidal *Eurydice* isopods from water, rather than land, during darkness: (i) *Eurydice* isopods are abundant in the surf zone, but are probably unavailable on shore because they bury themselves within just a few minutes of being stranded on exposed sand. It seems very unlikely that Storm-petrels would dig in the sand to search for such small and cryptic prey at night, and we do not find sand grains on the bill, legs or plumage of the Storm-petrels that we capture at our tape lures. Furthermore, the legs and bills of Storm-petrels do not seem to be well adapted for digging in the sand to search for prey. (ii) In the water column, *Eurydice* are abundant at night, but not during the day. (iii) The very fresh and undigested condition of the *Eurydice* specimens found in the vomit samples of nocturnally-captured Storm-petrels suggests that the birds had very recently ingested them.

We obtained live intertidal *Eurydice* sp. in our hand-netted surf samples throughout the nocturnal parts of the tidal cycle, and Figure 2 shows that the times at which Storm-petrels regurgitated undigested *E. naylori* and *E. affinis* in vomit are not restricted to the hours immediately around high tide.

Eurydice truncata and *E. inermis* are offshore species, found exclusively in the subtidal zone (Jones & Pierpoint 1997, Macquart-Moulin 1998). Both species bury themselves in the substrate on the sea floor during the day, and perform nocturnal vertical migrations of many metres, to forage at the sea surface by night (Jones & Naylor 1967, Macquart-Moulin 1998), when they may become available to foraging Storm-petrels. Thus, the occurrence of these species in the vomit of migrating Storm-petrels indicates that these individuals had been foraging offshore at night. It is noteworthy that some individual Storm-petrels had fed both on intertidal and offshore *Eurydice* species (see Table 1).

Studies at the breeding colonies indicate that Storm-petrels may regularly obtain food from the intertidal zone when they are anyway coming onshore to deliver food to their chicks. In a 5-year study of material regurgitated by Storm-petrels captured while attending two separate breeding colonies in the Bay of Biscay, 37% of identified prey items were inter-tidal taxa, including *Eurydice affinis* & *E. pulchra* (D'Elbée & Hémery 1998), showing that breeding Storm-

petrels routinely forage in the inter-tidal zone during summer nights –at least at these particular colonies (but see Scott (1970) for an apparently more pelagic diet among Storm-petrels attending a colony on Skokholm Island, S. Wales). Other records of Storm-petrels feeding on terrestrial invertebrates refer to insects that had probably been blown out to sea before being picked up from the sea surface by the birds (Voous 1954, Cramp & Simmons 1977).

The ability of Storm-petrels to feed on very small (~3-5mm) non-bioluminescent *Eurydice* isopods during darkness raises the question of how they locate and capture their prey. The European Storm-petrel does not have particularly large eyes compared to birds of equivalent body mass, and it has a relatively low retinal image brightness compared to other nocturnal birds (Thomas *et al.* 2004, & unpublished data). Such data imply that, although this species forages during darkness, it may not have particularly good nocturnal vision –though retinal and neural specialisations may allow Storm-petrels to see more detail in low light conditions than their small eye size might suggest. It is also possible that Storm-petrels detect their prey by smell (Roper 1999) or touch as well as -or instead of- by sight. The striking absence of other abundant potential prey taxa of the intertidal zone from any of the Storm-petrel vomit samples (see results) suggests that some feature of *Eurydice* behaviour or ecology must make them relatively available to foraging Storm-petrels.

The presence of fish remains and subtidal and offshore *Eurydice* species in the vomit samples in our study shows that migrating Storm-petrels do not forage exclusively on intertidal *Eurydice* isopods, and indeed the diversity of prey taken near the breeding colonies show that they are often generalist foragers (Cramp & Simmons 1977, D'Elbée & Hémery 1998). However, our results indicate that at least some Storm-petrels do forage close to the shore by night during migration, at a time in their annual cycle when they have previously been assumed to be exclusively pelagic. We believe that our observations are the first evidence for inter-tidal foraging in migrating (rather than breeding) European Storm-petrels, and they illustrate the kind of detailed behavioural information that can be inferred from combining the study of gut contents of migrating seabirds with information about the behaviour and ecology of their prey.

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BEWIJS VOOR 'S NACHT IN DE GETIJDEZONE FOERAGEREN DOOR STORMVOGELTJES *HYDROBATES PELAGICUS* TIJDENS DE TREK

Vroeger werd gedacht dat Stormvogeltjes *Hydrobates pelagicus* tijdens de trek uitsluitend pelagische foerageerders waren. In dit artikel presenteren we echter bewijs dat trekkende Stormvogeltjes 's nachts ook bij het strand foerageren. We benadrukken het herhaaldelijk voorkomen van de intergetijden crustaceeën *Eurydice naylori* & *E. affinis* (Isopoda: Cirolanidae) in de uitgebraakte voedselresten van Stormvogeltjes die tijdens hun noordwaartse trek langs ZW-Portugal werden gevangen om geringd te worden. De combinatie van de 'verse' staat van deze crustaceeën, hun biotoop, de beperkte verspreiding in de intergetijdezone en hun nachtelijke activiteitspatroon, indiceert dat de Stormvogeltjes die deze soorten hadden gegeten 's nachts in de intergetijdezone van zandstranden gefoerageerd hebben. We vonden ook *Eurydice*-soorten van de sublitorale zone in de uitgebraakte monsters, inclusief offshore-soorten *E. inermis* en *E. truncata* die beide 's nachts naar het zeeoppervlak migreren, hetgeen eveneens een aanwijzing is voor de plaats waar én het tijdstip waarop Stormvogeltjes foerageren. We benadrukken de nieuwe inzichten in het foerageergedrag van Stormvogeltjes, die verkregen kunnen worden door analyse van hun maaginhoud en het gedrag en de ecologie van hun prooisoorten.

REFERENCES

Bolton M. & Thomas R.J. 2001. Moult and ageing of Storm Petrels *Hydrobates pelagicus*. Ringing & Migration 20: 193-201.

Cramp S. & Simmons K.E.L. (eds.) 1977. *Birds of the Western Palearctic*, vol.1. Oxford University Press.

D'Elbée J. & Hémery G. 1998. Diet and foraging behaviour of the British storm petrel *Hydrobates pelagicus* in the Bay of Biscay during summer. Ardea 86: 1-10.

Harris P., Fowler J.A. & Okill J.D. 1993. Initial results of Storm Petrel *Hydrobates pelagicus* ringing in Portugal. Ringing & Migration 14: 133-134.

Jones D.A. & Naylor E. 1967. The distribution of *Eurydice* [Crustacea: Isopoda] in British waters, including *E. affinis* new to Britain. Journal of the Marine Biological Association of the United Kingdom 47: 373-382.

Jones D.A. & Pierpoint C.J. 1997. Ecology and taxonomy of the genus *Eurydice* (Isopoda: Cirolanidae) from sand beaches on the Iberian Peninsula. Journal of the Marine Biological Association of the UK 77: 55-76.

Macquart-Moulin C. 1998. Gut repletion during diel vertical migration in the benthopelagic crustacean *Eurydice truncata* Norman, 1868 (Isopoda, Cirolanidae). Journal of Plankton Research 20: 817-829.

Okill J.D. & Bolton, M. 2005. Ages of Storm Petrels *Hydrobates pelagicus* prospecting potential breeding colonies. Ringing & Migration 22: 205-208.

Roper T.J. 1999. Olfaction in birds. Advances in the Study of Behaviour 28: 247-332.

Salvat B. 1966. Isopodes Cirolanidae: taxonomie, éthologie, écologie, repartition verticale et cycle reproducteur. Actes de la Société Linnéenne de Bordeux: 103.

Scott D.A. 1970. The breeding biology of the Storm Petrel *Hydrobates pelagicus*. PhD thesis, Oxford University, UK.

Thomas R.J., Kelly D.J. & Goodship N.L. 2004. Eye design and visual constraints on behaviour. Ornitologia Neotropical 15: 243-250.

Valeiras J. 2003. Attendance of scavenging seabirds at trawler discards off Galicia, Spain. Scientia Marina 67: 77-82, Suppl. 2.

Voous K.H. 1954. Nog iets over het voedsel van Stormvogeltje, *Hydrobates pelagicus* (L.). Ardea 42: 217-218.

Wernham C.V., Toms M.P., Marchant J.H., Clark J.A., Siriwardena G.M. & Baillie S.R. (eds.) 2002. The Migration Atlas: movements of the birds of Britain and Ireland. T. & A. D. Poyser, London.