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Title: Thermal and trophic habitat of the leatherback turtle during the nesting season in French Guiana

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Abstract: Understanding environmental cues determining behaviour and habitat use of species of conservation concern is crucial if one aims at implementing sustainable management of these natural resources. In this way, here, we investigate the thermal and trophic conditions during the nesting season of the critically endangered leatherback sea turtle Dermochelys coriacea in French Guiana where high bycatch rates have been reported.

Mean sea water temperatures obtained in situ by animal-borne recorders were 26.6 ± 0.7 °C in the water column, with all but one turtle remaining in water >25 °C during the inter-nesting interval. In terms of prey availability, regular jellyfish stranding events were recorded during the nesting season, on a 1.25-km long section of the nesting beach. The occurrence of jellyfish was supported by benthic trawls performed on the continental shelf, with a total of 45.4 kg of jellyfish collected

exclusively in coastal waters 10 to 20 m deep where water transparency was between 0.8 and 3 m. This is consistent with the at sea distribution area of gravid leatherbacks during their inter-nesting intervals, as they spent almost 70% of their time diving in shallow (< 20 m deep) waters in front of the Maroni River estuary. In French Guiana, leatherback's gelatinous prey are present in very shallow water close to the nesting site and may be easily exploited by active gravid leatherbacks. This suggests that in French Guiana female leatherbacks may be influenced by local trophic conditions and actively prospect productive areas overlapping with local fisheries ground.

Suggested Reviewers:

Cover Letter

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Strasbourg, le 26 Décembre 2008

Pr. Hughes
Editor-in-chief,
Journal of Experimental Marine Biology and Ecology

Subject : revised ms Fossette et al. "Thermal and trophic habitat of the leatherback turtle during the nesting season in French Guiana"

Dear Editor,

Please find enclosed the revised version of our ms Fossette et al. entitled "Thermal and trophic habitat of the leatherback turtle during the nesting season in French Guiana" for publication in *Journal of Experimental Marine Biology and Ecology*.

This new version has been changed in light of the referees' comments to which we carefully replied directly in the ms (coloured text) and in the following pages where you will see how we have modified the text in line with the referee comments.

We have tried in our new ms, as the referees suggested, to stress on the fact that this study, considering the experimental design, mainly aims at describing the thermal and trophic habitat of leatherbacks rather than testing habitat preference. Accordingly, we performed new statistical analyses in order to better describe this habitat and to propose original hypothesises concerning the leatherback's distribution according to the local environmental parameters during the nesting season.

We hope you will be convinced by our reply to the referees and that we shall hear from you in the near future.

Yours sincerely,

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D08-444 Ref 1

We added to the manuscript all the references suggested by referee 1 and modified the text accordingly (see text highlighted in blue).

D08-444 Ref 2

We accepted all the suggested corrections (please see text highlighted in yellow).
We detailed the example from Hays et al. 2002 as asked (please see page 3).
We rewrote the paragraph "in-situ recorded temperatures" in material & methods (please see page 5).
As suggested, we perform an Anova to compare temperatures between years (please see page 7).
We perform a Kruskal-Wallis test to compare jellyfish stranding distribution between months (please see page 8)
As suggested, we changed the name of jellyfish species.
We added the two suggested hypotheses about the need of water during the nesting season to the discussion (please see page 11).

D08-444 Ref 3

Note 1: As suggested we modified the figure 1: we used an equal grid area to map leatherback habitat utilisation. We also provided more information on how we calculated time spent in grid cells (please see the text highlighted in purple in pages 4 and 5). We also added a figure with the positions of trawl lines plotted on the same map as leatherback's inter-nesting tracks.

Note 2: We added to the manuscript the suggested references and modified the text accordingly (Please see text highlighted in purple in pages 3, 4, 9, 12)

General comment :
As suggested, we added new statistical analyses to the manuscript in order to better describe the habitat of leatherback turtles during the nesting season. We statistically compared the distributions of SST values on the continental shelf and SST values spatially interpolated along the turtles' tracks in order to highlight the fact that turtles preferentially explore warm coastal waters between 27.0°C and 28.5°C. According to the bio-statistician of our laboratory, it was however not possible to perform more detailed statistics, such as Wilcoxon ranksum test, on these data because of the different statistical characteristics of the samples (i.e. SST values on the continental shelf are independent data contrary to SST values along the turtle's tracks which are intra-correlated).
For testing habitat preference against key environmental variables in a proper statistic way, it would have been necessary to have at each turtle's location and at the same time, a measure of the temperature and of the jellyfish abundance. This was however not feasible considering the temporal gap between the different data sets and the logistic difficulty to perform numerous trawls on the Guiana continental shelf. Considering this experimental design, our study therefore aims at describing the thermal and trophic habitat of leatherbacks rather than testing habitat preference. We thus modified accordingly the introduction and discussion of this ms. We notably highlighted the fact that leatherbacks and jellyfish are present in the same habitat:

warm and turbid coastal waters of the Guiana continental shelf, which was not previously expected considering the literature. This result allowed us to propose original hypothesises concerning the distribution of the leatherback turtles according to the local environmental parameters during the nesting season.

Thermal and trophic habitat of the leatherback turtle during the nesting season in French Guiana

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Running title: Environmental conditions of the leatherback's inter-nesting habitat

Summary

Understanding environmental cues determining behaviour and habitat use of species of conservation concern is crucial if one aims at implementing sustainable management of these natural resources. In this way, here, we investigate the thermal and trophic conditions during the nesting season of the critically endangered leatherback sea turtle Dermochelys coriacea in French Guiana where high bycatch rates have been reported.

Mean sea water temperatures obtained in situ by animal-borne recorders were 26.6 ± 0.7 °C in the water column, with all but one turtle remaining in water >25 °C during the inter-nesting interval. In terms of prey availability, regular jellyfish stranding events were recorded during the nesting season, on a 1.25-km long section of the nesting beach. The occurrence of jellyfish was supported by benthic trawls performed on the continental shelf, with a total of 45.4 kg of jellyfish collected exclusively in coastal waters 10 to 20 m deep where water transparency was between 0.8 and 3 m. This is consistent with the at sea distribution area of gravid leatherbacks during their inter-nesting intervals, as they spent almost 70% of their time diving in shallow (< 20 m deep) waters in front of the Maroni River estuary. In French Guiana, leatherback's gelatinous prey are present in very shallow water close to the nesting site and may be easily exploited by active gravid leatherbacks. This suggests that in French Guiana female leatherbacks may be influenced by local trophic conditions and actively prospect productive areas overlapping with local fisheries ground.

Keywords

Environmental conditions, jellyfish, water temperature, nesting season, sea turtles, spatial distribution, prey distribution

INTRODUCTION

Oceanographic conditions affect marine organisms either directly through individuals' physiology or indirectly through trophic resources (e.g. Bost et al., 1997; Guinet et al., 1997; Sims and Quayle, 1998; McMahon and Hays, 2006; Witt et al., 2007). In particular, water temperature and trophic conditions during the reproductive season have been reported to have wide-ranging and significant impacts on the nesting ecology of marine turtles (e.g. Buttemer and Dawson, 1993; Sato et al., 1998; Hays et al., 2002; Southwood et al., 2005; Wallace and Jones, 2008). For instance, recent evidence suggests that local trophic conditions may shape the activity of green turtles in their breeding grounds: when seagrass was abundant, breeding turtles spent most of their time foraging at very shallow depths while they rested at deeper depths on the seabed when food was not available (Hays et al., 2002). In the same way, water temperature on the Pacific coasts of Costa Rica has been reported to be closely linked to the diving behaviour of nesting leatherback sea turtles Dermochelys coriacea (Vandelli, 1761) as they spend a significant amount of their time at sea in waters <24 °C where they show low activity levels and low metabolic rates (Southwood et al., 2005; Wallace et al., 2005). In doing so, female leatherbacks may limit overheating while conserving energy for reproduction (Southwood et al., 2005; Wallace et al., 2005).

In French Guiana, where one of the world's major leatherback nesting sites occurs, gravid leatherbacks have been reported to disperse actively and extensively over the continental shelf during the nesting season while performing continuous benthic dives (Fossette et al., 2007; Georges et al., 2007) probably in order to feed on jellyfish (Fossette et al., 2008a). Importantly, this behaviour may partly explain the high rates of accidental catches of leatherbacks by coastal fisheries reported during the nesting season in this area (Fossette et al., 2008b, see also Witt et al., 2008). Indeed, interactions between leatherbacks and fisheries may result from turtles and fishermen actively searching for their respective food resources in similar areas over the Guiana continental shelf. Accordingly, understanding the mechanisms ruling both leatherbacks and fishermen behaviours is crucial if one aims at implementing sustainable management of natural resources while limiting interactions with species of any conservation concern such as sea turtles (e.g. Georges et al, 2007; Witt et al., 2008). However to date, leatherback's habitat off French Guiana has never been investigated so that the environmental parameters influencing sea turtles habitat use and behaviour during the nesting season still remain unknown.

Here we propose to describe the thermal and trophic (jellyfish distribution and abundance) conditions of leatherback's habitats during the nesting season in French Guiana and their potential connections with the spatial distribution and dive patterns of gravid females between two consecutive nesting events. In doing so, we aim at contributing to the implementation of more efficient protection of this critically endangered species.

MATERIAL AND METHODS

The study was carried out at Awala-Yalimapo beach (5.7 °N – 53.9 °W), French Guiana, South America, and on the Guiana continental shelf.

Leatherback's habitat use

Eleven gravid leatherback turtles tracked with Argos transmitters during their inter-nesting intervals in 2001, 2002 and 2003 (see Fossette et al., 2007 for more details). All tracks were processed as in Gaspar et al. (2006): first, Argos locations implying an apparent speed above 2.8 $m.s^{-1}$ were discarded; tracks were then smoothed and re-sampled every three hours.

For each re-sampled track, we calculated using R© software the number of locations per 0.1° * 0.1° area on the Guiana continental shelf, and then deduced the time spent in each area of 0.1° * 0.1° (Georges et al., 2007).

Thermal conditions on the Guiana continental shelf

Remotely-sensed Sea Surface Temperatures

We estimated remotely-sensed Sea Surface Temperatures (SSTs) on the Guiana continental shelf during the leatherback nesting seasons between 2001 and 2007 using monthly maps of AVHRR Oceans Pathfinder Version 5.0 SST data (4 km resolution; http://pathfinder.nodc.noaa.gov). These products are developed at RMAS and NODC and distributed in partnership with the Physical Oceanography Distributed Active Archive Center (PO.DAAC; see http://podaac.jpl.nasa.gov for details). We considered a surface area comprising the eleven inter-nesting tracks, i.e. between the French Guiana coast (approx. 5.5°N) and 7.5°N latitude, and 55-53°W longitude (see Fossette et al., 2007 for more details). In addition, we estimated SSTs along these inter-nesting tracks by bi-linear interpolation of the SST monthly fields.

In-situ recorded temperatures

Seven leatherback turtles were fitted with electronic Time-Depth Recorders (TDRs, Little Leonardo, Tokyo, Japan) during their inter-nesting intervals in 2001, 2002 and 2003 (Table 1, see Fossette et al., 2007 for more details). Each TDR included a temperature sensor recording one measurement of in situ temperature every 10 seconds (range: -20 to +80 °C, ± 0.1 °C). In-situ temperatures recorded by the loggers were averaged between 0 and 3 m depth (hereafter called 'in-situ surface temperature'), and between 3 m and the maximum depth (hereafter called 'in-situ column temperature').This threshold of 3 m was chosen in agreement with previous studies reported leatherback turtles remaining, between two successive dives, between 0 and 3 m depth alternating breathing and 'surfacing' dives (Reina et al., 2005; Fossette et al., 2007). In-situ temperatures were investigated throughout the inter-nesting interval in 12-hour intervals coinciding with local light/dark phases, as sea water temperature may vary between daytime and night time.

Trophic conditions on the Guiana continental shelf

Jellyfish stranding surveys

Jellyfish stranding were recorded during daily surveys of Awala-Yalimapo beach over 1.25 km of coastline from April to July 2005 (n = 76 days of survey) and 2006 (n = 92 days). Surveys were conducted two hours after the high tide when marine debris were left by retreating tides. Surveys lasted approximately one hour: two persons were patrolling the beach side by side, one from the shore to the middle of the beach, and the other one from the middle of the beach to the higher water mark. Observers were switching their respective place during the backward leg for controlling the counting of each other. Genus of each stranded jellyfish was identified and number of individuals observed in each genus was assessed. In addition, a total of 94 stranded jellyfish was randomly sampled during the 2005 nesting season, measured and weighted.

At sea jellyfish distribution and biomass

In May 2007, benthic trawls were performed through the "CHALOUPE" project, which aims at investigating changes in marine biodiversity structure of the Guiana continental shelf regarding impacts of the fishing activities and climate change (see http://www.projet-chaloupe.fr/). A total of 36 randomly located transects was performed between 4.7°N-6.3°N latitude and 53.7°W-51.5°W longitude, over depths ranging from 10 to 55 m. Trawls were performed by a shrimp trawler, at an average speed of 3-4 knots (5.5-7.4 km.h^{-1}) during 30 minutes. The trawl net was 11 m long with an opening of 1 m width and a 45 mm mesh size. For each trawl, jellyfish were separated from other collected species, before being identified to the genus level, counted and weighted. The turbidity was also measured during each transect using a Secchi disk.

RESULTS

Leatherback's habitat use

Based on the eleven inter-nesting tracks from Fossette et al. (2007), we calculated that turtles spent 68.3%, 20.6%, 10.1% and 1.0% of their time in waters <20 m, 50 m, 100 m, and 200 m depth respectively, and mainly explore waters in front of the Maroni River estuary (Figs 1, 2, 6).

Thermal conditions on the Guiana continental shelf

Remotely-sensed Sea Surface Temperatures

SSTs measured by satellite in the inter-nesting area (see material and methods) ranged from 25.5 °C to 29.5 °C (Fig. 3) and varied among years (Anova, $F_6 = 2497.23$, $P < 0.01$ followed by post-hoc Tuckey test, $P < 0.05$ in all cases; Table 2). Distributions of SST values on the continental shelf and SST values spatially interpolated along the turtles' tracks were statistically different ($\chi^2_6 = 52.2$, $P < 0.01$, Fig. 3).

In situ recorded temperatures

Mean (± S.D.) temperatures recorded by the TDRs were 27.4 ± 0.4 °C at the surface and 26.6 ± 0.7 °C in the water column with a minimum of 22.1 °C and a maximum of 34.7 °C, both experienced by turtle T200101 (Table 1 and Fig. 4). For each turtle in-situ temperatures varied throughout the inter-nesting interval (Table 1). The maximum variations were recorded for T200101 with 9.4 °C and 6.5 °C of difference at the surface and in the water column, respectively (Table 1) while the minimum variations were recorded for T200202 with 2.8 °C and 1.8 °C of difference at the surface and in the water column, respectively (Table 1). Figure 4 illustrates these two different temperature profiles and the corresponding dive profiles: T200101 experienced water column temperature ≤24 °C during 3.5% (9 h) of its inter-nesting interval when it reached the edge of the continental shelf and dived deeper than 60 m, while T200202 remained in shallow waters >27 °C during its entire inter-nesting interval. The other turtles did not experience water column temperature <25 °C and remained in shallow waters <30 m during their entire inter-nesting interval (Table 1).

Trophic conditions on the Guiana continental shelf

Jellyfish stranding surveys

A total of 1091 (14.4 ± 22.2 ind/survey) and 7095 (77.1 ± 155.1 ind/survey) jellyfish were recorded between April and July 2005 and 2006 respectively, on Awala-Yalimapo beach (Fig. 5). Daily number of stranded jellyfish was highly variable during both survey periods, the highest jellyfish stranding occurring in April every year (Kruskal-Wallis, in 2005, $H_{3,76}$ = 9.33, $P < 0.05$; in 2006, $H_{3,92}$ = 29.66, $P < 0.01$, Fig. 5). Conversely, very few stranding occurred in June and July 2005 and July 2006. Most of the jellyfish observed stranded on Awala-Yalimapo beach during the leatherback nesting season were Stomolophus sp. (Agassiz, 1862), and to a lesser extent to Aurelia sp. (Linnaeus, 1785) and Physalia physalis. (Linnaeus, 1758). Indeed from the 94 jellyfish randomly collected on the beach, 88 belonged to Stomolophus sp., and only 6 to Aurelia sp. (Table 3). Compared to Aurelia jellyfish, Stomolophus jellyfish were on average half the size and almost four times lighter (Table 3).

At sea jellyfish distribution and biomass

Stomolophus and Aurelia jellyfish were found in 7 out of the 36 benthic trawls, with a total biomass of 45.4 kg (range: 0.2-30 kg, Table 4, Fig. 2) for 2206 individuals (range: 33-1492 ind per haul, Table 4). Jellyfish biomass significantly increased when water depth decreased (Spearman's rank correlation, $R_s = -0.670$, $n = 36$, $p < 0.01$, Figs. 2, 6) and turbidity increased ($R_s = 0.673$, $n = 36$, $p < 0.01$, Figs. 2, 6). Indeed, benthic trawls collected jellyfish exclusively in waters where sea floor depth was between 10 and 20 m and water transparency between 0.8 and 3 m (Fig. 2, 6).

DISCUSSION

Foraging temperate habitats of the leatherback turtle have been previously described in terms of environmental temperature and prey distribution using different approaches in order to understand how the ocean environment may drive the spatiotemporal distribution of this species of conservation concern (e.g. Houghton et al., 2006, Mc Mahon and Hays, 2006, Witt et al., 2007). Similar studies have however never been performed in leatherback's tropical nesting areas. In the present study, we described for the first time the trophic and thermal conditions over the French Guiana continental shelf during the nesting season of leatherback turtles in order to highlight potential links between these environmental parameters and the dispersal and diving patterns of gravid females during their inter-nesting intervals.

In the study area, remotely sensed SST was relatively warm and homogeneous over the inter-nesting area but slightly variable among years (2001 to 2007) during the leatherback's nesting season, as previously reported at a larger scale by in situ oceanographic study (Frouin et al., 1997). In addition, SSTs within the area and along the turtles' tracks were different, suggesting that gravid leatherbacks preferentially explore warm areas (i.e. with surface temperatures comprised between 27.0°C and 28.5°C). In situ water column temperatures obtained by animal-borne recorders were also variable. Indeed, leatherback turtles that remained during their entire inter-nesting interval in shallow waters (<30 m deep) close to the shore (this study and Fossette et al., 2007) experienced relatively warm environment (>25 °C) throughout the entire water column, while turtles that explored deeper waters at the edge of the continental shelf (this study and Fossette et al., 2007) experienced a wider range of temperatures in the water column (down to 22 °C). This suggests that, in French Guiana, during an inter-nesting interval, leatherbacks may easily reach different thermal environments. Nevertheless, this study shows that in fact most of the leatherbacks rarely experience cool waters and remain in warm environment close to the shore in front of the Maroni River estuary as previously reported (Fossette et al., 2007; Georges et al., 2007).

This contrasts with studies in the Pacific coast of Costa Rica where leatherbacks have been reported to spend relatively more time in cool waters <24 °C (on average 9.5 ± 5.8%, and up to 19.0% of their time; Wallace et al., 2005) than in French Guiana (0.5 ± 1.3%, and up to 3.5% of their time, this study). Yet, leatherback turtles experience similar average temperatures in French Guiana and Costa Rica (26.6 ± 0.7 °C this study *vs* 25.9 ± 1.4 °C Southwood et al., 2005). In Costa Rica, leatherbacks have been reported to reduce activity levels while commuting between habitat of contrasted water temperatures to potentially avoid overheating and have relatively reduced energy expenditures during the inter-nesting interval (Wallace et al., 2005). If that was the case this suggests that there may be some physiological advantages for gravid leatherbacks to use different thermal environments when possible. In French Guiana the situation is however different since most of the leatherbacks remained in warm waters close to the shore (this study) and actively swim during their entire inter-nesting interval (Fossette et al., 2007) while they could easily shuttle to different thermal environments. In French Guiana, coastal waters are strongly influenced by enormous fresh water discharge from the adjacent rivers (Baklouti et al., 2007). By aggregating off the mouth of the Maroni river, gravid leatherbacks may thus extract the large amounts of water they need to produce eggs (Ackerman, 1997) directly from brackish water. This may be less energy consuming than drinking sea water. Another possibility for gravid female turtles to actively explore warm coastal waters is that they may be able to take advantage of favourable local food resources, illustrated by the abundance of jellyfish stranded and offshore, as detailed below.

Beach stranding events have been previously used as a qualitative index of the in-water presence and seasonality of jellyfish (e.g. Doyle et al., 2007a; Houghton et al., 2007). Indeed, Houghton et al. (2007) used beach stranding data to elucidate the foraging ecology of leatherback sea turtles in temperate latitudes. On our tropical study site, three species of jellyfish commonly eaten by leatherbacks, namely Stomolophus sp., Aurelia sp. and Physalia physalis (Bjorndal, 1997; Cogger, 2000; James and Hermann, 2001) stranded during the leatherback's nesting season, with the largest stranding recorded occurring in April, i.e. one month before the peak of leatherback's nesting activity. There was however large stranding also throughout the entire nesting season. These land-based observations indicate that jellyfish occur in waters immediate to the leatherback's nesting site during the breeding season and therefore could provide a suitable prey field to exploit during their nesting season. Consuming iso-osmotic organisms occurring in brackish waters like jellyfish in French Guiana may also help leatherbacks with their important water need during the nesting season. The hypothesis of leatherback turtles foraging during the nesting season is supported by their active, extended swimming and diving behaviour (Fossette et al., 2007; 2008a). However, it has to be noticed that in French Guiana, jellyfish species are smaller and apparently in lower densities than species usually eaten by leatherbacks at higher latitudes (Doyle et al., 2007b; Houghton et al., 2007). Therefore, even if turtles may find complementary food supply in their breeding site, local trophic conditions do not appear to be sufficient to sustain the high demands associated with reproduction (and the higher density of turtles), compared to higher prey densities leatherbacks do encounter during their migrations (Hays et al., 2004). Indeed, body mass of leatherbacks declines between high latitude foraging areas and nesting sites highlighting the absolute necessity of the migration to the foraging grounds at the end of the breeding season (James and Mrosovsky, 2004). Our observations also show important daily, monthly and annual variations in the number of stranded jellyfish on Awala-Yalimapo beach. These results, however, should be considered with caution since stranding events strongly depend on coastal currents: an absence of jellyfish stranding does not necessarily imply that they are absent from the water column (Doyle et al., 2007a; Houghton et al., 2007).

In addition to the beach stranding events of jellyfish, Continuous Plankton Recorder Survey data may be used in the NE Atlantic for constructing landscapes of gelatinous organism distribution and thus identifying probable foraging grounds for leatherback turtles in high latitudes (Witt et al., 2007). Such data are not available in leatherback's tropical nesting areas. In this study, benthic trawls conducted over the Guiana continental shelf complemented our land-based observations. Indeed, this offshore survey allowed us to detect the presence of jellyfish (mainly Stomolophus sp.) in the shallowest (between 10-20 m) and most turbid coastal waters. These waters influenced by both local rivers and Amazon river were previously refereed as "green" and "beige" waters (Froidefond et al., 2002). In contrast, no jellyfish were collected over deeper seabed in clearer waters. It is worth noting that the benthic trawl surveys probably underestimated the actual jellyfish abundance on the Guiana continental shelf since the gear mainly sampled the bottom of the water column even though some jellyfish might be caught in the rest of the water column while the net is returning to the surface. Therefore, benthic trawl surveys confirm the presence of leatherback's jellyfish prey on the Guiana continental shelf, in particular in shallow and turbid waters, but abundance and distribution estimations should be taken with caution. Our results are however in accordance with previous studies reporting gelatinous plankton in coastal and estuarine waters (e.g. Arai, 1992; Cabreira et al., 2006; Houghton et al., 2006; Doyle et al., 2007a; Houghton et al., 2007), including on the bottom (e.g. Alvarez Colombo et al., 2003). For instance, high concentrations of Rhizostome jellyfish (which includes Stomolophus sp.) have been previously associated with brackish waters (Perez-Ruzafa et al., 2002).

In addition, no jellyfish were found during benthic trawls carried out during the dry season when the turbidity of the waters and the Amazon influence are low (F. Blanchard, unpublished). This suggests that the flow of local rivers may influence the development of jellyfish in the area, probably through modifications of turbidity and/or salinity conditions on the Guiana continental shelf during the leatherback's nesting season.

Interestingly, leatherbacks clearly focused their activity during their inter-nesting intervals off the mouth of the Maroni River (this study, Fossette et al., 2007; Georges et al., 2007) where they performed bottom dives, interpreted as foraging dives (Fossette et al., 2007; 2008a). Although our results should be interpreted with caution since trawl surveys were not conducted in the river mouth itself, nor during the same years as the turtle's tracking, they suggest that in French Guiana, the gelatinous prey are notably present in shallow waters close to the nesting site and may be easily exploited by active gravid leatherbacks. Indeed leatherbacks may locate prey even in turbid coastal waters by using buccal pumping during dive (Myers et al., 2006, Fossette et al., 2008a). In addition, it has been recently suggested that gravid leatherbacks may adopt an optimum search strategy, where successive dive depths follow a mathematical distribution, in order to locate prey that are patchily distributed in the water column (Sims et al., 2008). This suggests that in French Guiana female leatherbacks would be more likely influenced by local trophic conditions than by thermal environment and thus actively explore productive areas where coastal fisheries also operate. In comparison, the low level of activity reported for leatherbacks in Costa Rica (Wallace et al., 2005) may be related to limited food availability. Unfortunately, to date, trophic context has not been investigated there. It is worth noting that it is now possible to directly track jellyfish and precisely record their depth (Hays et al., 2008) which will allow a better understanding of the linkages between turtle diving behaviour and jellyfish depth distribution.

Given the potentially environmentally-mediated strategies leatherbacks may adopt in the different nesting sites, and given the context of accelerated climate change and overfishing resulting in major shifts in marine ecosystems toward jellyfish dominance of food web (e.g. Purcell, 2005; Lynam et al., 2006; Attrill et al., 2007), a better understanding of the trophic relationships centred on jellyfish and jellyfish predators, such as the critically endangered leatherback, is crucially required for ensuring the sustainability of these natural resources. Novel tracking technologies such as fastloc GPS loggers by improving accuracy in tracking marine species (Schofield et al., 2007) will surely help to manage such studies and thus to resolve the underlying patterns of movement in great detail. This may notably highlight typical searching behaviour (e.g. Sims et al., 2008) and allow a better understanding of prey-predator relationships.

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Table 1. Summary of the in-situ recorded temperatures (surface and water column) in seven TDR-equipped gravid leatherback turtles during their inter-nesting interval in French Guiana during the nesting seasons 2001, 2002, and 2003.

Turtles ID no.	**Departure time**	**Trip duration (d)**	**Dive depth range (m)**	**Max/Min (diff.) in-situ surface temp (°C)**	**Max/Min (diff.) in-situ column temp (°C)**	**In-situ surface temperature (°C)**	**In-situ column temperature (°C)**
200101	16 May 2001, 00:26	10.8	[0-80]	34.7 / 25.3 (9.4)	28.6 / 22.1 (6.5)	27.2 ± 0.8	25.3 ± 1.3
200102	22 May 2001, 02:58	9.9	[0-30]	30.8 / 25.7 (5.1)	29.2 / 25.4 (3.8)	27.3 ± 0.5	26.6 ± 0.6
200103	28 May 2001, 23:46	10.1	[0-20]	30.3 / 27.1 (3.2)	28.3 / 25.6 (2.7)	27.3 ± 0.6	27.0 ± 0.1
200201	30 Apr 2002, 23:30	12.1	[0-40]	29.7 / 26.5 (3.2)	29.3 / 26.0 (3.3)	27.4 ± 0.6	26.8 ± 0.3
200202	02 May 2002, 22:55	8.2	[0-30]	30.0 / 27.2 (2.8)	28.7 / 26.9 (1.8)	28.1 ± 0.6	27.4 ± 0.3
200301	05 May 2003, 22:43	9.3	[0-20]	29.2 / 25.9 (3.3)	27.9 / 25.9 (2.0)	26.9 ± 0.4	26.4 ± 0.2
200302	06 May 2003, 22:05	9.2	[0-30]	29.8 / 26.4 (3.4)	29.3 / 26.3 (3.0)	27.4 ± 0.5	26.8 ± 0.2
Mean ± s.d.				30.6 ± 1.9 / 26.3 ± 0.7	28.8 ± 0.5 / 25.5 ± 1.6	27.4 ± 0.4	26.6 ± 0.7

Values are expressed as mean ± s.d.

Table 2. Remotely-sensed Sea Surface Temperatures on the Guiana continental shelf (coast-7.5°N/ 55-53°W) for months of May 2001 to 2007.

		May 2001	May 2002	May 2003	May 2004	May 2005	May 2006	May 2007
SST (°C)	Mean ± s.d.	27.4 ± 0.6	27.2 ± 0.6	26.7 ± 0.4	27.3 ± 0.5	28.5 ± 0.3	27.8 ± 0.3	27.7 ± 0.4
	Min / Max	25.7 / 29.0	25.4 / 28.4	25.6 / 28.4	25.7 / 29.4	27.7 / 29.8	26.8 / 29.0	26.9 / 29.4

Table 3. General characteristics of 94 stranded jellyfish randomly sampled on Awala-Yalimapo beach during the 2005-2006 leatherback's nesting season.

Genus	N	Size (cm)	Mass (g)
Stomolophus sp	88	5.9 ± 2.8	32.2 ± 47.2
Aurelia sp.	6	11.2 ± 3.6	127.6 ± 58.5

Table 4. Jellyfish abundance and biomass in seven benthic trawls of 30 minutes each performed by a shrimp trawler on the Guiana continental shelf in May 2007.

Trawls	Date/Time	Abundance	Total biomass (g)	Individual biomass (g)	Depth (m)
1	12 May 2007, 15:59	82	1800	22.0	14.7
2	13 May 2007, 06:29	33	200	6.1	19.1
3	13 May 2007, 15:58	71	2000	28.2	17.9
4	15 May 2007, 16:22	1492	30000	20.1	10.7
5	16 May 2007, 10:25	160	3400	21.3	15.4
6	18 May 2007, 12:15	128	3000	23.4	16.8
7	18 May 2007, 15:36	240	5000	20.8	12.8
Total		2206	45400		
Mean ± SD		315 ± 523	6486 ± 10475	20.3 ± 6.8	15.3 ± 2.9

Legends

Fig. 1. Topographic representation of habitat use in terms of time spent per 0.1° * 0.1° area (blue squares) by leatherback turtles (n = 11; Argos tracked leatherback turtles nesting in French Guiana between 2001 and 2003) during the inter-nesting intervals on the Guiana continental shelf.

Fig. 2. Inter-nesting movements (solid black lines) of 11 Argos tracked leatherback turtles during the nesting season 2001, 2002 and 2003 in French Guiana and distribution of jellyfish sampled by bottom trawling on the Guiana continental shelf in May 2007. Trawling with successful and unsuccessful jellyfish sampling are represented by circles and crosses respectively. The size of each circle indicates the jellyfish biomass. Colours of the crosses and circles indicate water transparency: light grey means water transparency > 3m, dark grey means water transparency between 2.0-3.0m, and black means water transparency between 0.8-2.0m depth.

Fig. 3. Frequency distribution of remotely-sensed SSTs in the area off French Guiana [coast-7.5°N / 53-55°W] during the leatherback nesting season (in grey) and along the tracks of 11 leatherback turtles during their inter-nesting interval in 2001, 2002 and 2003 (from Fossette et al., 2007; in black).

Fig. 4. Dive depth (solid black line), in-situ recorded temperatures (at surface: open circles, in water column: filled circles) throughout the inter-nesting interval for two TDR-equipped leatherback turtles nesting in French Guiana (one in 2001 and the second in 2002).

Fig. 5. Daily (solid black line) and monthly (mean ± s.d.: black dots ± error bars) number of stranded jellyfish on Awala-Yalimapo beach between April-July in 2005 (n = 76 daily surveys) and April-July in 2006 (n = 92 daily surveys).

Fig. 6. Relationship between jellyfish biomass, water transparency and sea floor depth obtained from random bottom trawling between 10 m and 55 m depth on the Guiana continental shelf by a shrimp trawler in May 2007. Trawling with successful and unsuccessful jellyfish sampling are represented by circles and crosses, respectively. The size of each circle indicates the jellyfish biomass. Insert: percentage of time spent by leatherback turtles (n = 11; Argos tracked leatherback turtles nesting in French Guiana between 2001 and 2003) at different depths during the inter-nesting intervals on the Guiana continental shelf.

Figure

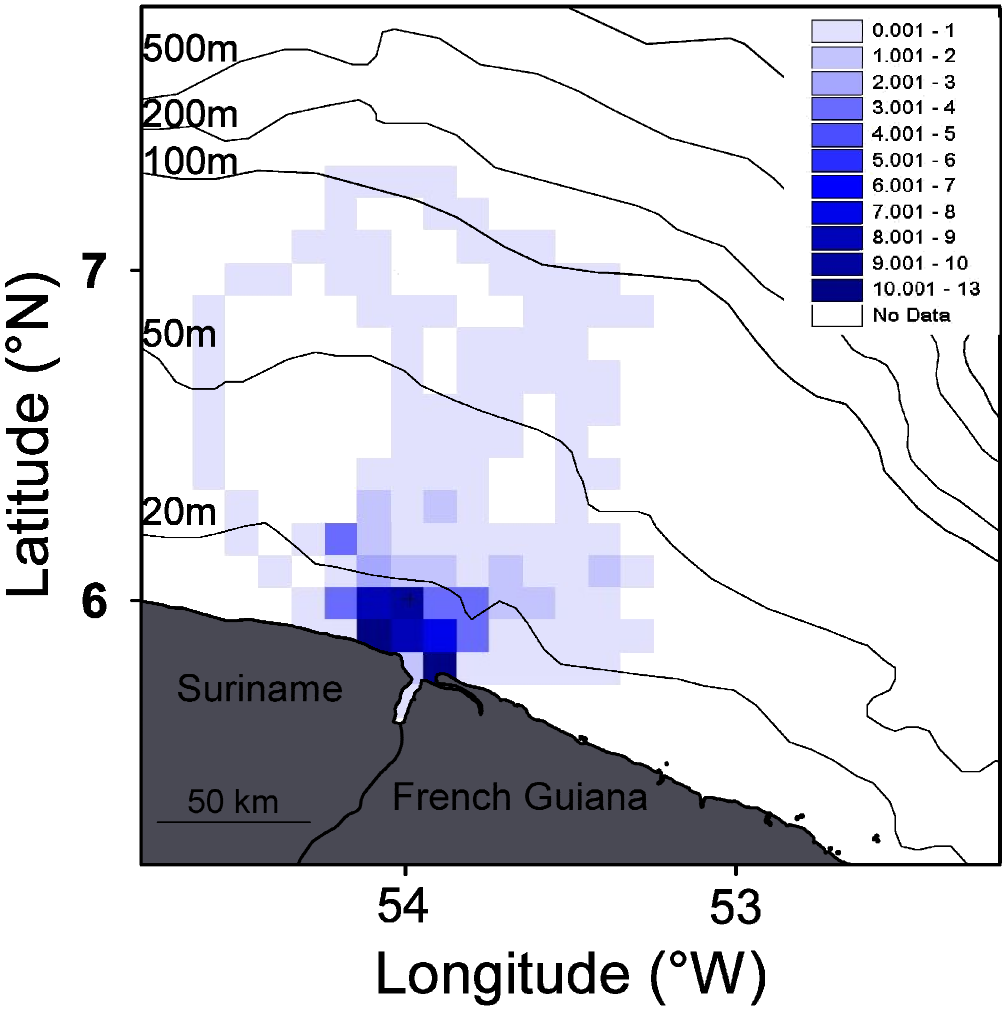
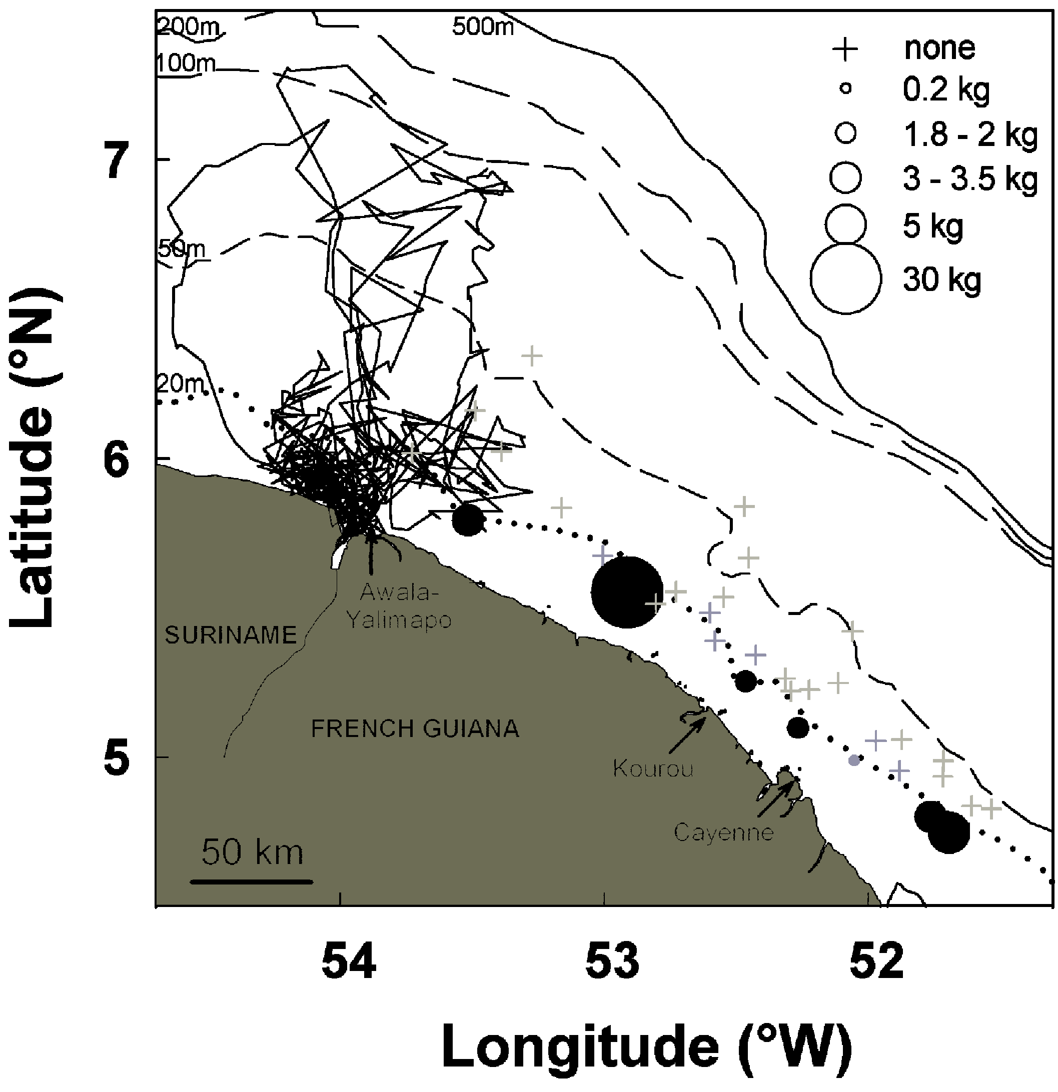
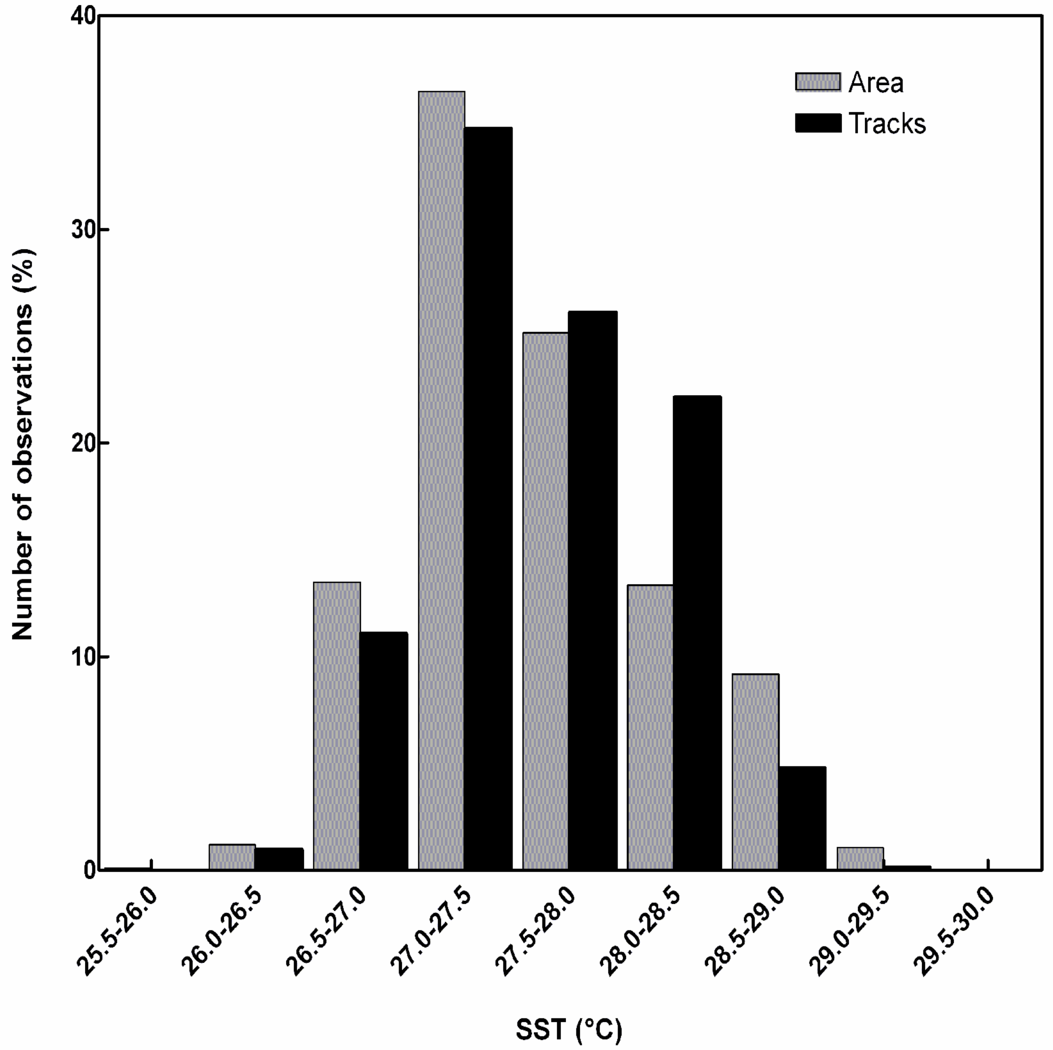

500m
200m
100m
50m
20m
0.001 - 1
1.001 - 2
2.001 - 3
3.001 - 4
4.001 - 5
5.001 - 6
6.001 - 7
7.001 - 8
8.001 - 9
9.001 - 10
10.001 - 13
No Data
7
6
Latitude (°N)
Suriname
French Guiana
50 km
54
53
Longitude (°W)

Fig. 1



200m
100m
500m
50m
20m
none
0.2 kg
1.8 - 2 kg
3 - 3.5 kg
5 kg
30 kg
7
6
5
Latitude (°N)
Awala-
Yalimapo
SURINAME
FRENCH GUIANA
Kourou
Cayenne
50 km
54
53
52
Longitude (°W)

Fig. 2



Area
Tracks
Number of observations (%)
0
10
20
30
40
25.5-26.0
26.0-26.5
26.5-27.0
27.0-27.5
27.5-28.0
28.0-28.5
28.5-29.0
29.0-29.5
29.5-30.0
SST (°C)

Fig.3

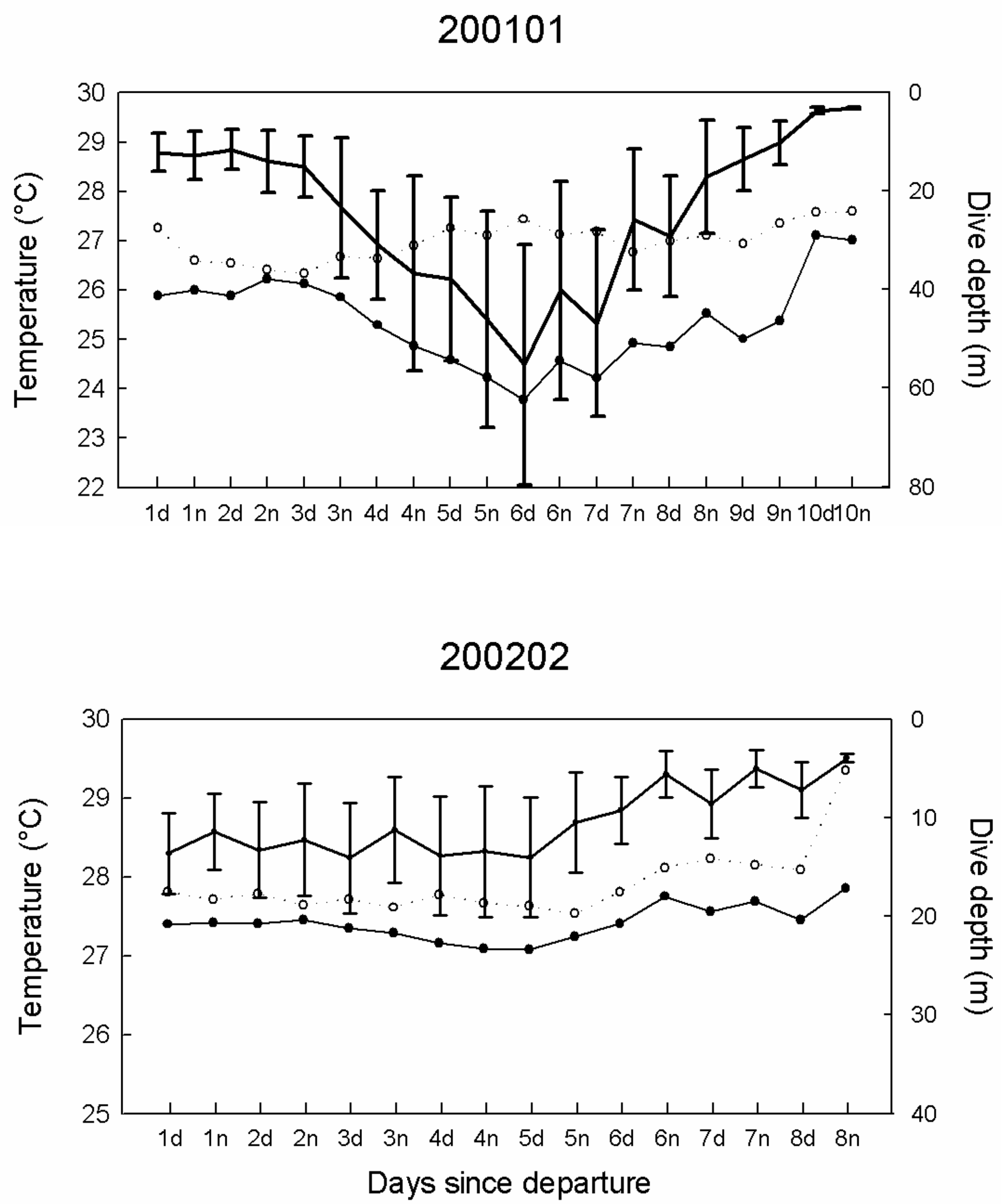
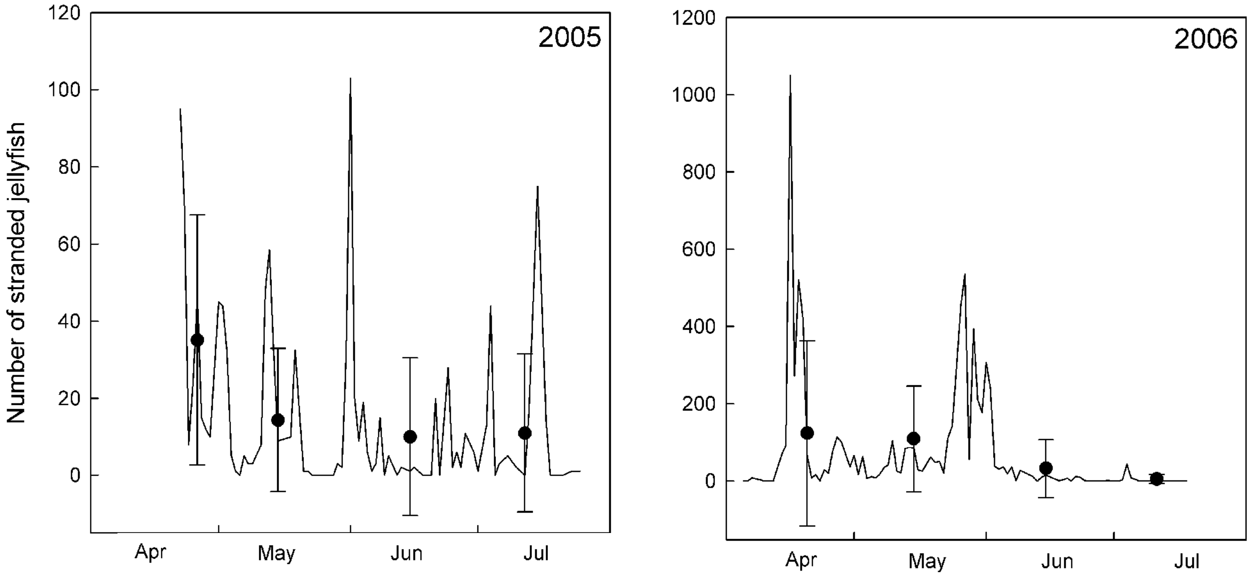

200101
Temperature (°C)
Dive depth (m)
30
29
28
27
26
25
24
23
22
0
20
40
60
80
1d 1n 2d 2n 3d 3n 4d 4n 5d 5n 6d 6n 7d 7n 8d 8n 9d 9n 10d 10n
200202
Temperature (°C)
Dive depth (m)
30
29
28
27
26
25
0
10
20
30
40
1d 1n 2d 2n 3d 3n 4d 4n 5d 5n 6d 6n 7d 7n 8d 8n
Days since departure

Fig. 4



2005
2006
Number of stranded jellyfish
120
100
80
60
40
20
0
1200
1000
800
600
400
200
0
Apr
May
Jun
Jul
Apr
May
Jun
Jul

Fig. 5

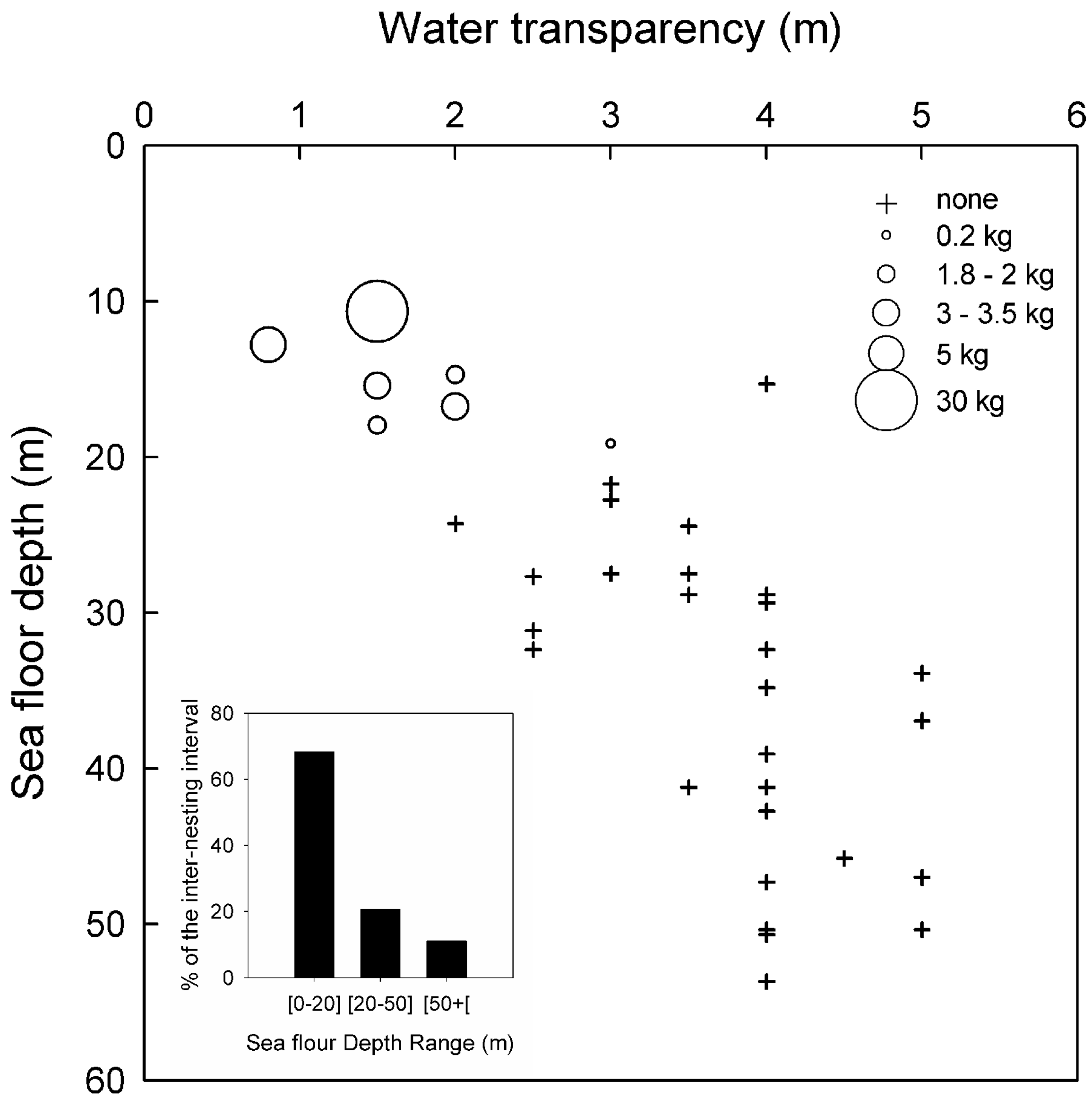

Water transparency (m)
0
1
2
3
4
5
6
0
10
20
30
40
50
60
Sea floor depth (m)
none
0.2 kg
1.8 - 2 kg
3 - 3.5 kg
5 kg
30 kg
% of the inter-nesting interval
80
60
40
20
0
[0-20]
[20-50]
[50+[
Sea flour Depth Range (m)

Fig.6