CHAPTER 5. SPATIAL DISTRIBUTION OF SEA TURTLES

5.1 CHAPTER SUMMARY

Indices of relative sea turtle density from trawl captures and sightings from aerial surveys were combined to generate maps of the relative spatial distribution of sea turtles along the Queensland east coast. The analysis was undertaken to gain insights into factors influencing the relative distribution of sea turtles in feeding-grounds across a wide spatial scale. As expected, sea turtles were not evenly distributed throughout the aquatic habitats of the Queensland east coast. Several areas had an exceptionally high relative density of sea turtles. Relative sea turtle density, as indicated by sea turtle catch rate in trawled areas, was significantly correlated with the type of target species trawled and water-depth. *Natator depressus* and *Lepidochelys olivacea* had high relative densities in inshore tropical waters <40m deep, where tiger prawns (*Penaeus esculentus*, *P. semisulcatus*) and endeavour prawns (*Metapenaeus endeavouri*, *M. ensis*) were the main target species caught. *Caretta caretta* had high relative densities in inshore sub-tropical waters <30m, where banana prawns (*Fenneropenaeus merguiensis*) or bay prawns (*Metapenaeus bennettae* i.e., Moreton Bay) were the main species caught. Spatial differences in the distribution of each species could be used to focus conservation management efforts in different areas for different species of sea turtle. The methods of determining broad scale in-water sea turtle densities presented in this chapter allowed the development of initial maps of relative sea turtle density across a large and diverse geographic area. Dedicated aerial surveys and replicated stratified trawl surveys designed to sample sea turtle abundance could be used to validate the predicted sea turtle densities. The maps of relative sea turtle density presented in this chapter are a starting point for identifying candidate areas for further intensive research or conservation-management e.g., ensuring high compliance of the use of Turtle Excluder Devices by trawlers operating in critical sea turtle areas.

5.2 INTRODUCTION

Human impacts on sea turtle populations need to be managed efficiently and effectively if sea turtle stocks are to recover from their depleted status (Magnuson *et al.* 1990). Managing impacts in feeding-grounds is important because the survival rates of sub-adult and adult sea turtles, which spend most of their time in feeding-grounds (this thesis, Chapter 2, section 2.3), have significant impacts on population trends (Heppell *et al*. 1999).

5.2.1 Current knowledge of sea turtle distribution in feeding-grounds

Knowledge of the general distribution of sea turtles in feeding-ground habitats is based on their diets and foraging habits and observed densities during feeding-ground research. As a result of extensive research by the Queensland Turtle Research Group (QTRG) (Limpus 1981; Limpus 1992; Limpus 1994; Limpus *et al.* 1984a; Limpus *et al.* 1994a; Limpus *et al.* 1994b; Tucker *et al.* 1995; Walker 1994; Chaloupka and Limpus 2001), the general distribution of each sea turtle species is known for northern Australia (see Chapter 2, section 2.4.2). However, the spatial distribution of the relative densities of sea turtle species is poorly quantified (Dr Colin Limpus, QPWS, personal communication 1998) and there are no broad scale maps of relative density at the scale of the entire Queensland east coast for any species of sea turtle. Currently, there is insufficient information on the location of key feeding-grounds for effective management (Dobbs 2001). This problem is not unique to Australia. Recently, there has been greater emphasis placed on the expansion of sea turtle research to include the distribution, abundance and trends in the population size of sea turtles in feeding-ground habitats (Mortimer *et al.* 2000; TEWG 1998). This area of research is referred to as ‘in-water’ research, to distinguish it from research that occurs on land at nesting beaches.

5.2.2 Estimating sea turtle density in feeding-grounds

In-water surveys of sea turtles in feeding-grounds are difficult because sea turtles spend most of their time submerged (see Chapter 4) and individuals from a sub-population may be dispersed throughout numerous feeding-grounds that can be geographically separated by large distances (Limpus *et al.* 1992). This poses difficulties in applying sampling methods that are suitable for estimating sea turtle abundance in a variety of feeding-ground habitats and providing comparable results.

The main methods of surveying in-water sea turtle abundance over large areas have been: (i) capture in fishing equipment such as trawl nets or set gill nets (Butler *et al.* 1987; Dickerson *et al.* 1995; Epperly *et al.* 1995b; Poiner and Harris 1996); and (ii) sightings on feeding-grounds via aerial surveys (Marsh and Saalfeld 1989; Epperly *et al.* 1994, 1995a; Preen *et al*. 1997; McDaniel *et al.* 2000). Sea turtle density in selected feeding grounds (e.g., coral reefs) has been estimated from rodeo-capture information (Chaloupka and Limpus 2001).

Fishing surveys

The catch rate of sea turtles in fishing gear (e.g., trawl nets, set gill nets, pound nets) has been used to estimate the density of sea turtles in localised areas and in some fisheries (Butler *et al.* 1987; Poiner and Harris 1996; Bjorndal and Bolten 2000). Sea turtle catch per unit of effort (CPUE) is used as an index of in-water sea turtle density. Sea turtle CPUE in fishing operations is a limited index of sea turtle abundance because it is representative only of the areas or habitat types sampled by the fishery (Thompson *et al*. 1991; Henwood 2000). However, all methods of sampling the abundance of organisms have limitations (Andrew and Mapstone 1987) and this is true of other in-water survey techniques for sea turtles such as rodeo-capture (Limpus and Reed 1985b). Sea turtle CPUE from trawl fisheries does not provide representative samples from very shallow areas (i.e., <5m, but this is fishery-dependent) or from non-trawlable areas such as coral reefs and closed areas. However, sea turtle CPUE from trawl fisheries can provide representative samples of in-water sea turtle densities in deep or turbid water, which are areas poorly sampled by other methods such as rodeo-capture, underwater visual census and aerial survey. More recently, the USA Turtle Expert Working Group (TEWG) considered that trawl surveys are “probably the best currently available means of obtaining information on the in-water abundance of sea turtles” (TEWG 2000, p. 25).

Aerial surveys

Sightings from aerial surveys have been used to estimate relative density distributions, identify areas of high sea turtle density and estimate minimum population sizes (LeBuff and Hagan 1978; Marsh and Saalfeld 1989; Shoop and Kenney 1992; Epperly *et al.* 1994; Musick *et al.* 1994; Witzell 1999; Coles and Musick 2000; McDaniel *et al.* 2000). Aerial surveys typically count the number of sea turtles visible during a flight along pre-determined transects and as such is a measure of sighted sea turtle density.

Sighted sea turtle density can vary with water turbidity and substrate type (Lawler and Marsh 2002) and is affected significantly by survey height and sea state (Bayliss 1986; Marsh and Sinclair 1989a). Not all sea turtles present in an area will be sighted during an aerial survey (Marsh and Saalfeld 1989, Thompson *et al*. 1991; Preen *et al.* 1997, Epperly *et al*. 1995a). Sighted sea turtle densities can be corrected for observer bias i.e., the proportion of animals visible in a transect, but missed by the observer (Marsh and Sinclair 1989b). However, it is more difficult to extrapolate sighted sea turtle densities to total in-water densities because of the variability in reported proportions of time spent near the surface (i.e., not submerged) for sea turtles of various sizes and species (see Chapter 2, section 2.6.1). As such, aerial surveys provide a minimum estimate of sea turtle density in turbid inshore areas (Marsh and Saalfeld 1989; Shoop and Kenney 1992), as occurs along much of the central and southern Great Barrier Reef World Heritage Area. It is also difficult to identify sea turtle species (except for *Dermochelys coriacea*) and to sight small (<36 cm CCL) sea turtles during aerial surveys (Marsh and Saalfeld 1989; Marsh and Sinclair 1989a; Thompson *et al.* 1991; Epperly *et al.* 1995a). However, sighted sea turtle densities from aerial surveys provides relative distribution information that is useful when planning conservation measures or identifying seasons and areas where sea turtles may interact with fishing activities (Epperly *et al*. 1995a; Witzell 1999; McDaniel *et al.* 2000).

Sea turtle catch rates in trawl fisheries and sightings from aerial surveys provide separate estimates of relative in-water sea turtle density and are complementary techniques in the types of habitats sampled adequately. In combination, capture rates in trawl fisheries and sightings from aerial surveys may provide great insight into the relative spatial distribution of sea turtles in feeding-grounds. Quantitative spatial distributions of sea turtles across large geographic areas are a fundamental requirement for the conservation-management of sea turtle populations.

5.2.3 Aims of this chapter

In this chapter, I examined the relative in-water spatial distribution of sea turtles in waters adjacent to the Queensland east coast, based on sea turtle capture frequency in the trawl fishery and sightings from aerial surveys. I investigated the factors that influenced the catch rates of sea turtles (i.e., sea turtle CPUE) to develop a method of predicting in-water sea turtle density based on target species trawled (i.e., fishing sector as an indicator of habitat type) and water-depth. Areas of high in-water sea turtle density were identified from the predicted sea turtle CPUE and compared to areas of high in-water sea turtle density identified by the aerial surveys. This information was then used to identify areas of high priority for management (e.g., impacts from fishing) or conservation planning (e.g., marine protected areas, representative areas program).

5.3 METHODS

5.3.1 Sea turtle density calculated from trawl captures

Sea turtle capture data

Sea turtle CPUE (sea turtles caught per day fished) was calculated from sea turtle captures reported during the sea turtle by-catch monitoring program. Details of the program are provided in Chapter 3, section 3.3.1. Sea turtle capture information was matched to corresponding effort information recorded in the compulsory logbook program run by the Queensland Fisheries Service. About half the fishing effort in the Queensland East Coast Trawl Fishery is reported on a per-tow basis while the remainder is reported on a per-day basis. Therefore, the most basic unit of effort in the Queensland East Coast Trawl Fishery is a ‘day of fishing’. Fishers participating in the sea turtle by-catch monitoring program are referred to as the ‘sample fleet’ to distinguish catch and effort information for all vessels in the Queensland East Coast Trawl Fishery, referred to as the ‘total fleet’.

Calculation of sea turtle CPUE

There are several ways of calculating sea turtle CPUE; the optimum choice depending on the question being asked. In Chapter 3, stratifying the data into fishing sectors was appropriate for estimating the number of sea turtles annually caught by the Queensland East Coast Trawl Fishery. However, in this chapter, I was interested in estimating the relative in-water density of sea turtles across a large geographic area (i.e., Queensland east coast) at a scale useful for management. Therefore, sea turtle CPUE per unit area was considered the most appropriate index of in-water sea turtle abundance. Daily sea turtle CPUE was calculated according to the method of Poiner and Harris (1996). The catch of a sea turtle during a day of fishing was assumed to be a random event and independent of other captures. At most, five turtles were recorded caught on any single day of fishing by a single vessel in the sample fleet. Therefore, on any given day of fishing by a vessel, there was a probability of catching zero (P_0), one (P_1), two (P_2), three (P_3), four (P_4) or five (P_5) sea turtles, where $P_0 + P_1 + P_2 + P_3 + P_4 + P_5 = 1$

The mean daily catch rate was calculated as:

$$R = \sum_{i=0}^{5} iP_i = P_1 + 2P_2 + 3P_3 + 4P_4 + 5P_5 \ ,$$

with a variance (V) of

$$V = P_1 + 4P_2 + 9P_3 + 16P_4 + 25P_5 - R^2$$

As explained in Chapter 3 (section 3.3.2), fishers participating in the Queensland East Coast Trawl Fishery can record their daily catch and effort at a spatial resolution of: (i) 30^2nm (=1,668 km^2), referred to as a CFISH grid; (ii) 6^2nm (=66.7 km^2), referred to as a CFISH site; or (iii) as a point position specified by latitude and longitude (which is converted to the appropriate CFISH site). Mean sea turtle CPUE per CFISH grid was calculated for CFISH grids with ≥30 days of sample fleet fishing effort. Mean sea turtle CPUE per CFISH site was calculated for CFISH sites with ≥10 days of sample fleet fishing effort. Spatial representations of the observed sea turtle CPUE (as presented in the results) were formulated using a Geographic Information System (Arcview 3.2™).

Analysis of factors affecting sea turtle CPUE

Sample fleet effort and sea turtle catch information that included depth-trawled was used as a subset to investigate the factors influencing sea turtle catch rates. Only data provided at a spatial resolution of 6^2nm (i.e., CFISH site) was used in the analysis. Data provided at a spatial resolution of 30^2nm (i.e., CFISH grid) were not used because of the large variability in many factors that occur within a 30^2nm CFISH grid, such as water-depth and type of habitat fished. The subset of data where depth-trawled was known represented 7,989 days of fishing during which 1,242 sea turtles were captured. Daily counts of sea turtle captures per vessel were stratified by: (i) main target species trawled (= fishing sector) i.e., tiger prawns, endeavour prawns, banana prawns, red spot king prawns, eastern king prawns, scallops or Moreton Bay (see Chapter 3, section 3.3.2, Table 3.2); (ii) depth (= water-depth) i.e., 10 m intervals up 60 m, with depths >60 m being pooled; (iii) season i.e., non-nesting (March to September) or nesting (October to February); and (iv) nesting-ground status i.e., whether the location was a nesting-ground or feeding-ground.

The main target species trawled (i.e., fishing sector) was based on the commercial species caught that had the greatest weight of catch on each day fished. This factor was included in the analysis as an index of various aspects of the aquatic habitats trawled. For example, banana prawns (*Fenneropenaeus merguiensis*) are generally associated with turbid waters over muddy substrates, whilst red spot king prawns (*Melicertus longistylus*) are generally associated with clear waters in inter-reef areas (Williams 2002). Likewise tiger prawns (*Penaeus esculentus*) are often associated with areas adjacent to seagrass beds, while eastern king prawns (*Melicertus plebejus*) are often associated with sandy substrates. Stratification by fishing sector also included an inherent latitudinal component as each target species is associated with a certain latitude range e.g., red spot king prawns are caught generally in waters north of 21°N, 150°S; while eastern king prawns are caught generally in waters south-east of this point (Dredge and Trainor 1994; Robins and Courtney 1999; Williams 2002). This encompasses the suspected distributions of some sea turtle species in tropical versus sub-tropical waters (see Chapter 2, section 2.4.1 and 2.4.2). For example, Limpus *et al.* (1983a) and Parmenter (1994) suggest that the main feeding-grounds of *N. depressus* are primarily north of the Tropic of Capricorn, and Limpus and Reimer (1994) report that returns of *C. caretta* tagged at nesting beaches are concentrated between Gladstone and the Gold Coast i.e., south of the Tropic of Capricorn.

Water-depth was included as a factor in the analysis because sea turtle captures are generally recognised to vary with depth, being greatest in shallow waters (i.e., <30 m Henwood and Stuntz 1987; <40 m Poiner and Harris 1996). Nesting-ground status was included as a factor in the analysis because sea turtles aggregate at nesting areas, and generally have a higher relative density in waters adjacent to nesting-grounds than in feeding-grounds. The stratification of nesting-ground status was based on the geographic location of sea turtle rookeries as identified by the Queensland Turtle Research Project. Dr Colin Limpus (QPWS) provided the nesting distribution database of sea turtles in Queensland for this analysis. I fully acknowledged that sea turtle density is likely to be influenced by factors not considered in the above analysis. However, the available data limited the analysis to the factors of fishing sector (as an index of aquatic habitat), water-depth, season and nesting-ground status.

Sea turtle CPUE data were highly skewed, with a large number of days with zero sea turtle captures and was best modelled using a generalized linear model of counts with a Poisson distribution and a log-link function[10] (McCullagh and Nelder 1989). The factors fishing sector, water-depth, season and nesting-ground status were fitted in GENSTAT™ (2000) for all species combined and each individual species except *L. olivacea*. No significant nesting-grounds for *L. olivacea* are reported for the Queensland east coast, so the analysis for *L. olivacea* used the factors fishing sector, water-depth and season. The mean sea turtle CPUE (sea turtles caught per day fished) and associated standard errors were estimated from the generalized linear model (GLM).

Bathymetry estimates

One of the objectives of estimating mean sea turtle CPUE from the GLM was to then predict sea turtle CPUE at a location based on factors such as aquatic habitat type as indicated by fishing sector (i.e., target species caught), water-depth, season or nesting-ground status, depending upon which factors significantly influenced sea turtle CPUE. To do this required estimates of water-depth for all areas of the Queensland continental

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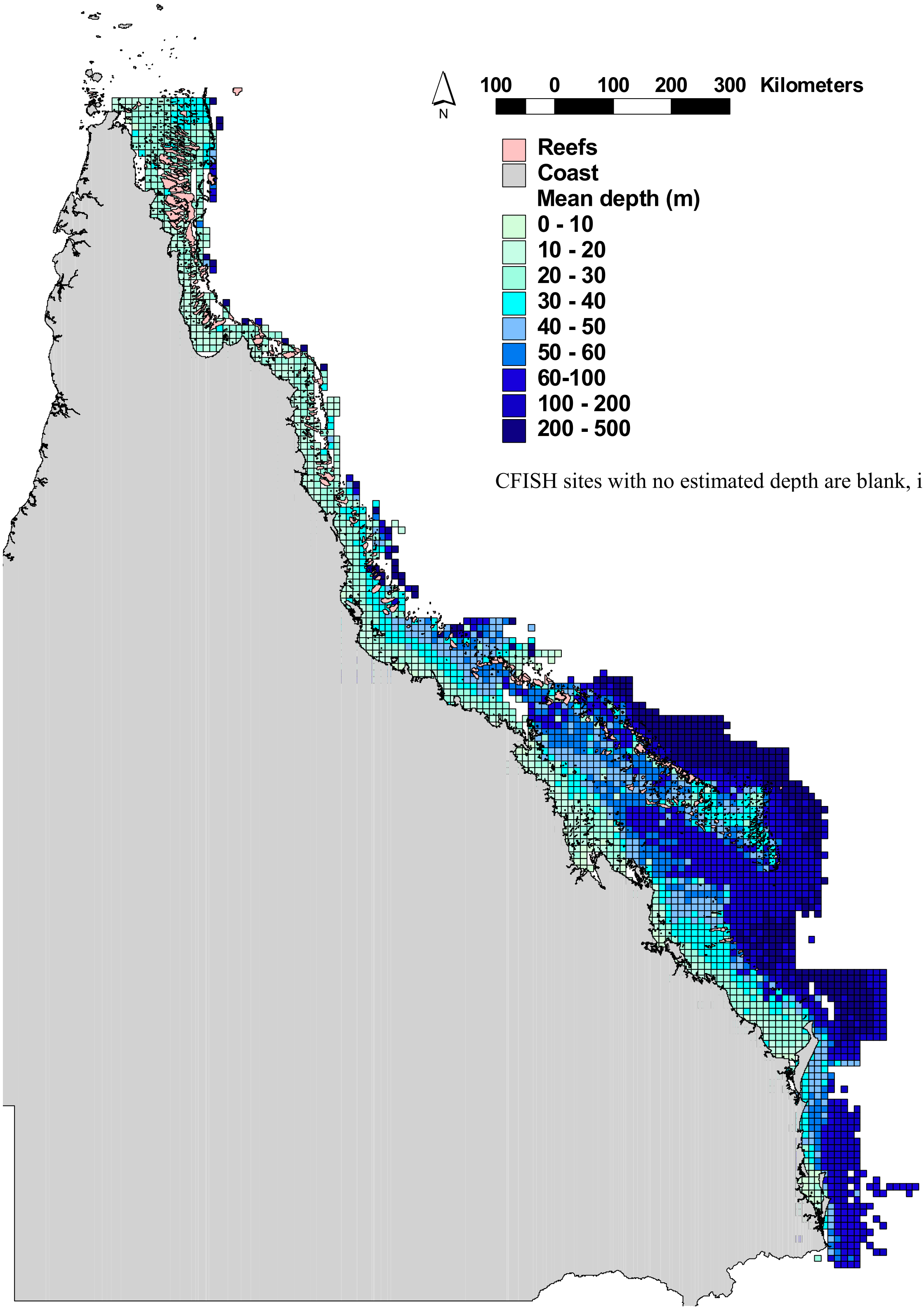
[10] Data analysis was conducted in consultation with Dr David Mayer, Principal Biometrician, QDPI.

shelf. These data are not readily available at small depth intervals. Therefore, estimates of water-depth per CFISH site were derived primarily from depth-trawled information reported by commercial fishers. About 208,500 records of mean depth-trawled per day were recorded in commercial logbooks of the Queensland East Coast Trawl Fishery between 1991 and 2000. CFISH sites where the standard deviation of mean depth-trawled was zero (i.e., no variation) or with <10 records (i.e., low sampling) were excluded from the analysis because of suspected poor reliability of the estimate of mean depth-trawled. In addition, CFISH sites with water-depths of >500 m were excluded from the analysis because they are beyond the east Australian continental shelf and there were no corresponding sea turtle CPUEs for these water-depths. Mean depth-trawled was estimated for 1,781 CFISH sites. Gaps in the mean-depth trawled data were supplemented by estimated water-depth modelled from hydrographic surveys and interpolation of water-depth contours. Modelled water-depth was provided by Dr Adam Lewis (GBRMPA). These two sources of estimates of water-depth were combined to provide an approximate mean water-depth per CFISH site for most locations on the continental shelf of the Queensland east coast. The final distribution of mean water-depth (Figure 5.1) was composed of the mean depth-trawled for 1,781 CFISH sites and mean water-depth from modelled bathymetry information for 1,250 CFISH sites where mean-depth trawled data were not available.

Figure 5.1 Mean depth per CFISH site estimated from logbook and modelled bathymetry data for waters up to 500 m deep



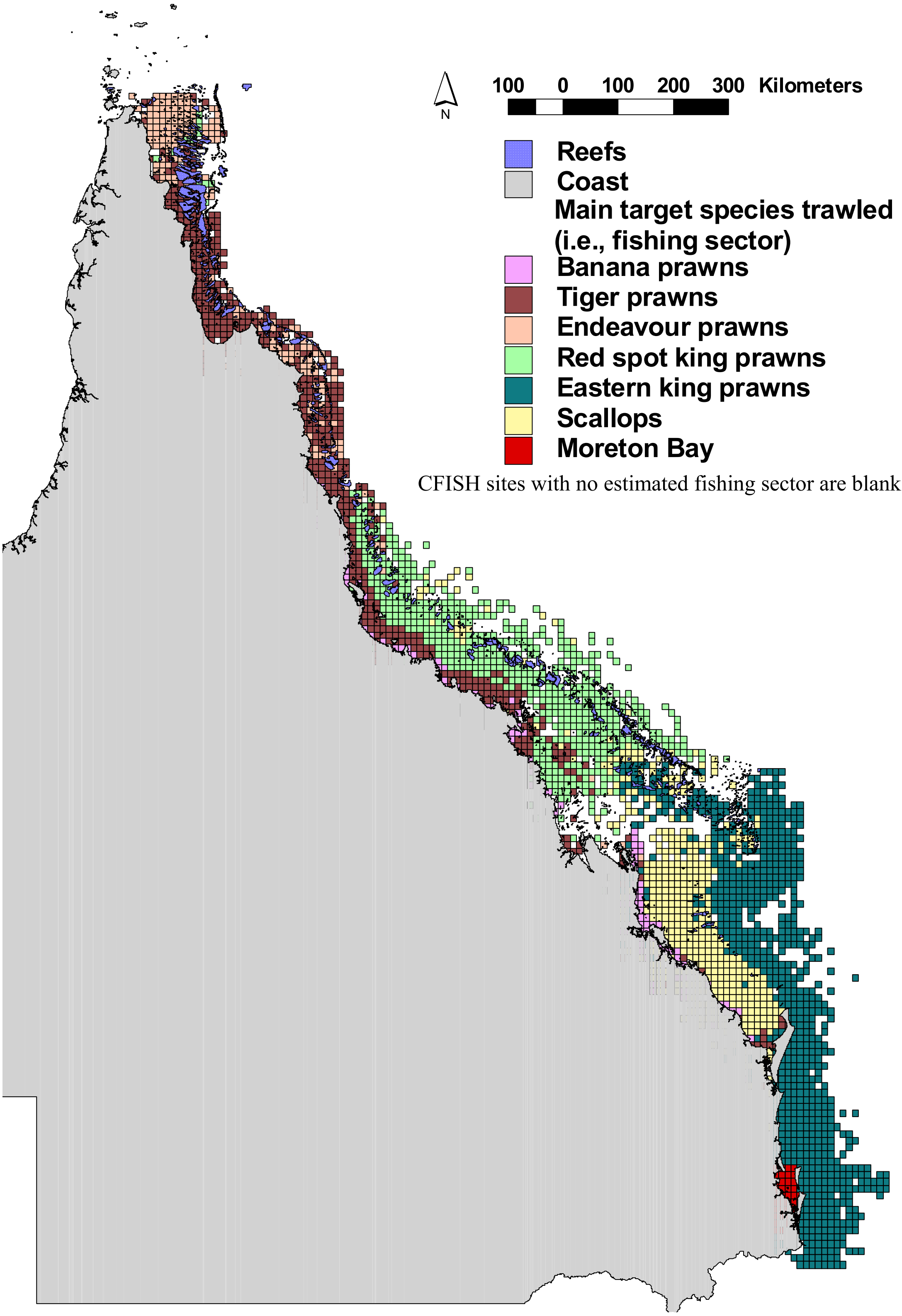
CFISH sites with no estimated depth are blank, i.e., white.

Aquatic habitat index estimates based on main target species trawled

The prediction of sea turtle CPUE for the majority of the Queensland east coast also required an estimated index of the aquatic habitat within a CFISH site, as represented by the main target species trawled. Commercial target catch data provide one of the few indications of the habitat and substrate type of trawl grounds at a relatively small scale (i.e., 6^2nm CFISH sites) across a large geographic area (i.e., the continental shelf of the Queensland east coast ~226,900 km^2). Auster *et al*. (2001) reported that species distributions from trawl survey data could be used as proxies for the distribution of aquatic habitats and that the species distributions based on trawl-surveys could be used to infer the habitat requirements of co-occurring species.

The main target species trawled per CFISH site was estimated from daily catch information reported by commercial fishers. About 353,200 records of daily catch were recorded at a spatial resolution of 6^2nm (i.e., CFISH site) in the commercial logbook database of the Queensland East Coast Trawl Fishery between 1991 and 2000. Fishing sector was allocated to each day fished, based on the target species caught with the greatest weight. Because of unequal days of fishing per year, the main target species trawled (i.e., fishing sector) per CFISH site per year (i.e., annual fishing sector for each year from 1991 to 2000) was determined by the target species caught that had the greatest proportion of days fished for which that species was the main target species trawled by weight. The fishing sector of a CFISH site was determined as the fishing sector that was most frequently allocated as the annual fishing sector (Figure 5.2). The exception to this was the allocation of fishing sector to ‘Moreton Bay’, which is a spatially defined sector of the Queensland East Coast Trawl Fishery for research and management purposes (see Chapter 3, Section 3.3.2, Table 3.2; Dredge and Trainor 1994; Robins and Courtney 1999).

Figure 5.2 Fishing sector per CFISH site, based on most frequent target catch per year for 1991 to 2000



CFISH sites with no estimated fishing sector are blank, i.e., white.

Predicting sea turtle CPUE

The mean sea turtle CPUE per CFISH site was estimated from the full GLM model. This predicted sea turtle density for 3,031 CFISH sites where estimates of mean water-depth and fishing sector were available. I acknowledge that water-depth and fishing sector are not the only factors involved in sea turtle distribution or in determining sea turtle densities and as a consequence the spatial distributions of predicted sea turtle density should be viewed as preliminary, but are the best estimate given the available data.

Classification of sea turtle CPUE

Sea turtle CPUE was divided into intervals so that the relative sea turtle density (i.e., sea turtle CPUE) could be presented spatially on a graded scale. Numerous methods of determining the intervals were considered[11] in light of the following criteria: (i) could be applied to the observed and predicted sea turtle CPUE; (ii) could be compared to the sea turtle density derived from aerial survey sightings; (iii) provided differentiation in the middle range of sea turtle CPUE (i.e., low to high); (iv) could be interpreted biologically if possible; and (v) resulted in four to five categories to maximise the visual interpretation of sea turtle CPUE represented spatially as a graded colour scale of relative density.

One of the desired attributes of the categories was their application to the observed and the predicted sea turtle CPUE. Thresholds at either end of the scale were not difficult to identify (i.e., very low and very high), but it was difficult to identify the appropriate divisions between these extremes. Equal-interval splitting of sea turtle CPUE was not feasible due to the strong skewness of the underlying data (i.e., the large number of true zero sea turtle CPUEs). A heuristic transformation[12] using the 95% cumulative frequency as per Slater et al. (1998) was considered, but failed to differentiate amongst the mid-range sea turtle CPUE, and was not comparable between observed and predicted values or all species and individual species.

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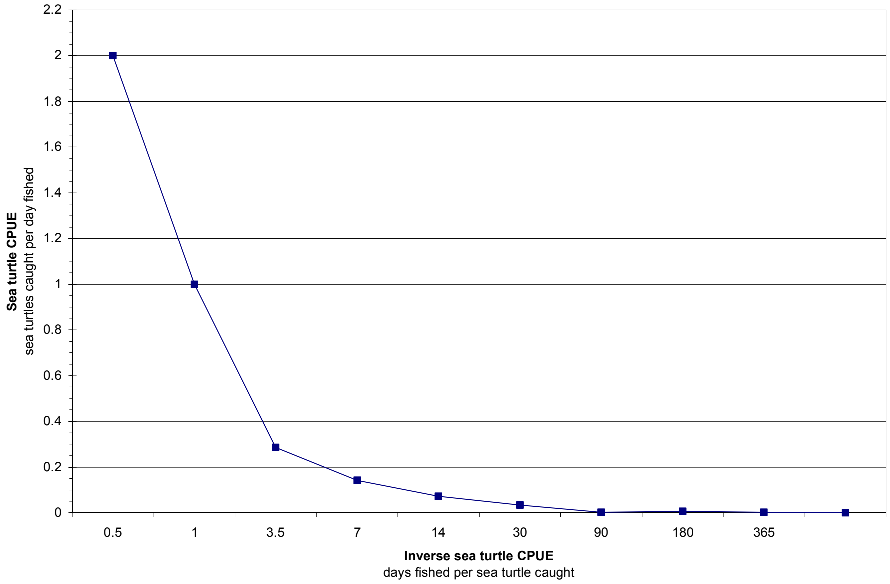
[11] Rationales of determining the class division were discussed with Dr David Mayer, Principal Biometrician, QDPI.

[12] The heuristic transformation involved finding the 95% cumulative frequency (V) for sea turtle CPUE, changing all values >V to V, dividing sea turtle CPUE by V and multiplying by the number of desired categories (Slater *et al.* 1997).

Another method considered was the geometric progression of the inverse of sea turtle CPUE (Figure 5.3), with inverse sea turtle CPUE being equivalent to the number of days fished per sea turtle caught. For example, a sea turtle CPUE of 0.0055 was equivalent to 182 days fished per sea turtle caught. Using a geometric progression of the inverse of sea turtle CPUE had an advantage of providing a tangible measure of relative sea turtle density (i.e., the quantity of fishing effort expended per sea turtle caught) that could be readily interpreted by fishers and managers.

Figure 5.3 Geometric progression of inverse sea turtle CPUE versus sea turtle CPUE



The geometric progression of sea turtle CPUE was divided into five classes with larger class divisions at the extremes (Table 5.1), because once sea turtle density reached a threshold i.e., very low or very high, not much additional information was gained by splitting these values.

Table 5.1 Class divisions of sea turtle CPUE

Class	Sea turtle CPUE Sea turtles caught per day fished		Comment Days fished per sea turtle caught
	Lower	Upper	
Zero	0	0	No sea turtles caught.
Very low	0.00001	0.00549	More than 180 days of fishing per sea turtle caught.
Low	0.00550	0.01111	Between 180 and 90 days of fishing per sea turtle caught.
Medium	0.01112	0.03333	Between 90 and 30 days of fishing per sea turtle caught.
High	0.03334	0.14286	Between 30 and 7 days of fishing per sea turtle caught.
Very high	>0.14286		Less than 7 days of fishing per sea turtle caught.

This approach also provided differentiation amongst mid-range sea turtle CPUE. The main consequence of the classification was that CFISH sites classified as ‘very high’ often had sea turtle CPUEs >0.143 (i.e., one sea turtle caught per seven days of fishing) and included extremely high values of observed sea turtle CPUE (e.g., 1.600). This reduced the resolution of the relative spatial distribution of sea turtles. However, this thesis examines relative sea turtle density in the context of managing fishing impacts, and as such any CFISH site with a sea turtle CPUE >0.143 would be a priority for management. A different class division (e.g., equal-area) might be relevant if one was solely interested in the relative distribution of sea turtles for biological reasons.

5.3.2 Sea turtle density calculated from aerial survey sightings

Professor Helene Marsh provided data on the frequency of sightings of sea turtles during aerial surveys of the Queensland east coast, whose main purpose was to count dugongs (Marsh and Lawler, 2001a; Marsh and Lawler, 2001b). These surveys covered inshore areas between 11°30’S to 26°00’S (Fraser Island) and the area 27°S to 28°S (Moreton Bay). The surveys used tandem observer methodology and were conducted according to the standardised protocols established by Marsh and Sinclair (1989b) and Marsh and Saalfeld (1989). Daily surveys were flown at times of the day to minimise glare and were only conducted during fair weather and Beaufort Sea states below three. The aerial surveys used strip-transect methodology, with the majority of transects being aligned east-west. The Queensland east coast was split into seven blocks and surveyed between October 1999 and December 2000 (Figure 5.4)[13]. Data from sections of transects that were broken to focus on counting high density occurrences of dugongs were not included in the analysis.

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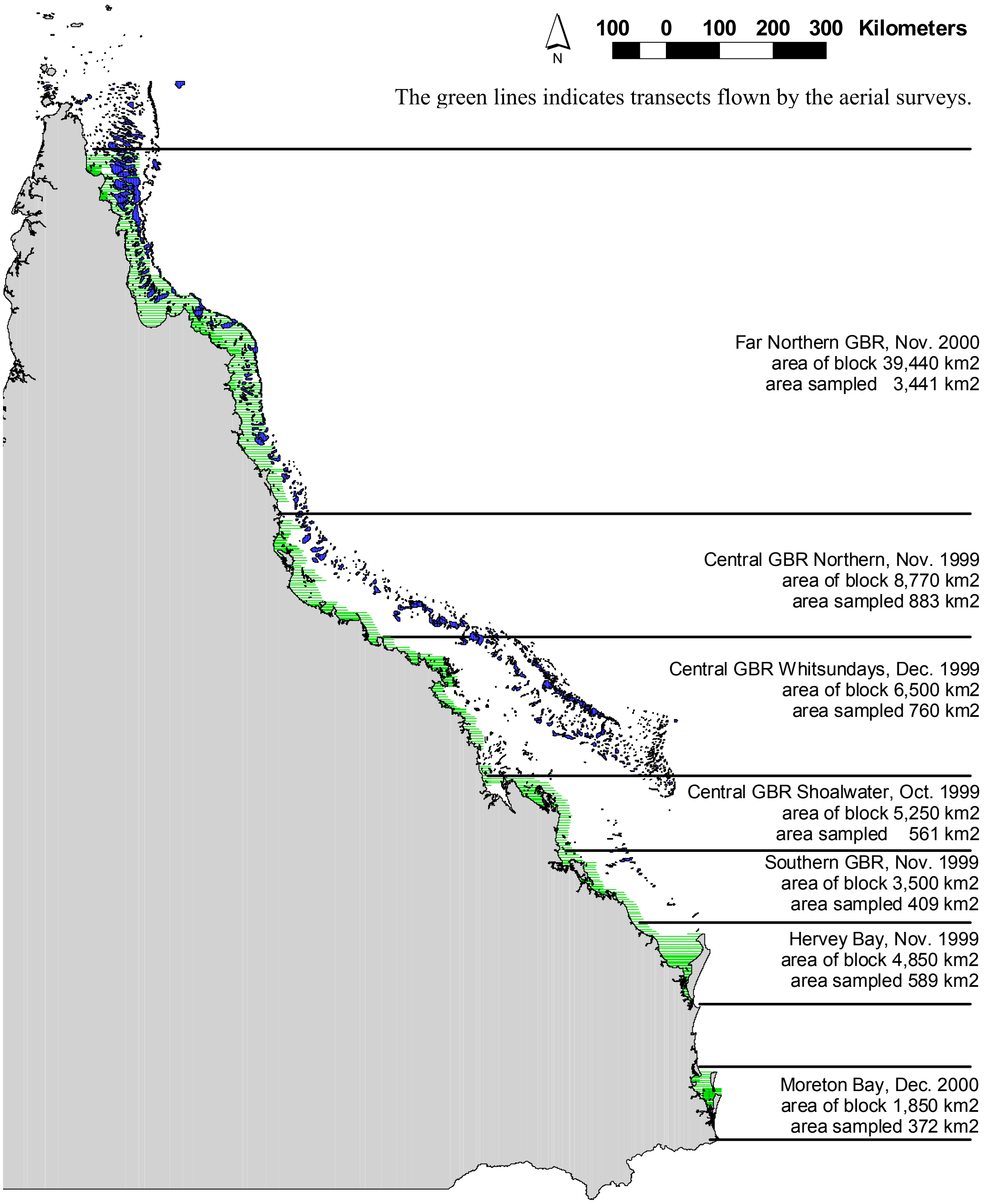
[13] The author participated in the following aerial survey blocks: Central GBR Shoalwater and Central GBR northern.

Figure 5.4 Aerial survey blocks from which sea turtle sightings were used to derive relative sighted sea turtle density



The position of all groups of sea turtles sighted within a transect were estimated to a latitude-longitude position and estimates of the counts of groups of sea turtles were corrected for perception bias i.e., "groups of turtles visible on the transect line that were missed by observers" (Marsh and Saalfeld 1989, p 242). Perception bias (=perception correction factor or PCF) was estimated for each team of observers (i.e., for port and starboard) for every survey block by the following formula:

$$\mathrm{PCF} = \frac{(S_m + b)(S_r + b)}{b(S_m + S_r + b)}$$

$$\begin{aligned} \text{where } S_m &= \text{sighting by mid - seat observers} \\ S_r &= \text{sighting by rear - seat observers} \\ b &= \text{sighting by both observers} \end{aligned}$$

$$\text{And N, or total number of groups} = \mathrm{PCF} * \text{Total seen}$$
$$\text{where Total seen} = (S_m + S_r + b)$$

Estimates of the counts of groups of sea turtles were not corrected for availability bias i.e., groups of sea turtles not available to observers because they were concealed by vegetation or turbid water (Marsh and Sinclair 1989b). Sea turtle sightings were not corrected for availability bias because there is large variability in the reported proportions of time spent near the surface for sea turtles of various sizes and species (see Chapter 2, section 2.6.1).

Sea turtle sightings (turtles per km^2)

The density of sighted sea turtles was estimated using aerial survey strip-transect methodology. In essence, sea turtle sightings within a designated strip width on either side of the flight path were counted and the density of animals within that strip was assumed to be representative of the area sampled. Because the strip transects were of variable length and area, the ratio method of Jolly (1969) was used to estimate density:

$$\hat{D} = \frac{Y_T}{Z_T},$$

the density of sea turtles in the area surveyed, and

$$Y_T = \sum_{i=1}^{n} y_i, \text{ the total number of sea turtles sighted during a survey,}$$

$$\text{where } y_i = \text{the number of groups of sea turtles sighted in the } i^{th} \text{ transect}$$

and

$$Z_T = \sum_{i=1}^{n} z_i, \text{ total area surveyed (km}^2\text{),}$$

$$\text{where } z_i = \text{the area surveyed in the } i^{th} \text{ transect (km}^2\text{)}$$

$$\text{and } n = \text{the number of strip transects sampled.}$$

For estimation of sea turtle density, the strip-transects were divided into areas equivalent to spatial scales at which the commercial trawling information was recorded. The relative density of sea turtle sightings (sea turtles per km^2) was calculated for each CFISH site (6^2nm = 66.7 km^2) and CFISH grid (30^2nm = 1,668 km^2) surveyed.

Classification of sea turtle sightings

The density of sea turtle sightings was divided into five categories so that the relative density of sighted sea turtles could be presented spatially on a graded scale. The divisions were similar to that used by Marsh and Saalfeld (1989), but with two extra classes (Table 5.2). One additional class distinguished between 'no sea turtles sighted' (i.e., zero sea turtles per km^2) and 'few sea turtles sighted' (i.e., <0.5 sea turtles per km^2). The other additional class divided areas where between 0.5 and 2.0 sea turtles per km^2 were sighted.

Table 5.2 Class divisions of aerial survey sea turtle sightings (sea turtles per km^2)

Class Marsh and Saalfeld (1989) Sea turtles per km^2	**Sighted sea turtle density** Sea turtles per km^2	**Class this study**
<0.50	0	Zero (no sea turtles sighted)
	0.01 to 0.50	Low
0.50 to 2.00	0.50 to 1.00	Medium
	1.00 to 2.00	High
>2.00	>2.00	Very high

5.3.3 Assumptions and inherent difficulties of these methods

Fishery-dependent sampling

Sea turtle catch per unit effort (sea turtles caught per day fished) was used as a measure of relative in-water sea turtle density. Sea turtle CPUE was dependent on the information reported by commercial fishers participating in the sea turtle by-catch monitoring program. As stated previously (Chapter 3, section 3.3.6), a criticism of fishery-dependent sampling is the possibility of bias resulting from small or unrepresentative sampling and possible inaccurate reporting by fishers (Murphy and Hopkins-Murphy 1989). About 100 fishers participated in the sea turtle by-catch monitoring program and displayed a diverse range of fishing patterns (see Chapter 3, section 3.4.1). Because of the voluntary nature of the program, commercial fishers who caught or killed many sea turtles may not have volunteered to record such information. It is also possible that commercial fishers who caught or killed few sea turtles would not be likely to volunteer to record such information because fishers consider that zero capture data are not important. Therefore, biases in the sea turtle CPUE as a consequence of non-random representation were unquantified and the direction of any possible effect was unknown. If fishers inaccurately reported details of sea turtles caught, then the observed sea turtle CPUE will be under-estimated. The degree of inaccurate reporting should be variable because participating fishers had variable levels of integrity. Variation in sea turtle CPUE (real or as a consequence of deliberate manipulation) was reflected in the standard errors of the estimated mean sea turtle CPUE. Concerted effort from the majority of the commercial fishers who participated in the sea turtle by-catch monitoring program would have been required to have a major effect on data accuracy (Robins 1995).

Differing units of measurement of sea turtle density

The indices of sea turtle density derived from trawl captures and aerial surveys were measured in different units i.e., sea turtle CPUE measured the number of sea turtles caught per day of trawling while aerial surveys measured the number of sea turtles sighted per km^2. This was (and is) an inherent difference between the estimates of relative sea turtle density derived from trawl and aerial surveys. Sea turtle CPUE (sea turtles caught per day fished) can be converted to sea turtles caught per km^2 fished, providing that the area swept by trawl nets during a day of fishing is known or estimates of swept area are assumed to be constant. This requires knowledge of: (i) the size and number of nets fished; (ii) the spread and height of the nets when fishing i.e., net opening area; (iii) the mean tow duration; and (iv) the mean tow speed (e.g., 3.2 knots). This information is not a mandatory requirement of the Queensland Fisheries Service catch and effort logbook. The diversity of the participants in the sample fleet (i.e., boat length and sectors fished) made it difficult to assume averages representative of all participants in the sample fleet for the parameters needed to estimate the area swept per day fished, particularly for net spread and tow speed.

Areas not sampled

The relative spatial distributions of sea turtles derived from the trawl capture and aerial survey data were limited to areas sampled by either the trawl fleet or the aerial surveys. Only limited estimates of sea turtle density were available for some areas, particularly the mid- and outer-shelf reefs from Cairns (~17°S) to the Swains Reef Complex (~22°S). The trawl effort in these areas is relatively low and as stated earlier, trawling does not sample reef habitats. The aerial surveys did not extend to the seaward limit of the Great Barrier Reef, as the surveys were designed to sample dugongs, with sea turtles being a secondary objective (Marsh and Lawler 2001a; Marsh and Lawler 2001b). In addition, the aerial surveys were conducted during the months of October, November or December and as such may be biased by the aggregation of sea turtles near breeding grounds. Not all sea turtles on a feeding ground migrate to breed each year (Miller 1996), therefore relative densities of sea turtles sighted during aerial surveys should still indicate the relative importance of various feeding-grounds. The relative spatial distributions of sea turtles generated in this chapter are limited by the factors listed above. However, the spatial distributions generated encompass the areas where trawl fishing occurs and as such encompass the area where sea turtle by-catch in trawl fisheries is an issue.

Time differences in sampling between trawl survey and aerial survey

I have drawn upon two different sets of data to infer relative sea turtle density along the Queensland east coast. The data sets were collected in different years. The trawl capture data were collected from 1991 to 1996 while the aerial survey data were collected in

1999 and 2000. Earlier aerial survey data were not used because no other set of aerial surveys covered the entire Queensland east coast within a short time-frame. Trawl capture and aerial survey data were analysed for broad scale trends in relative sea turtle distribution across a large geographic area. The time-lag between the data sets could be a problem if significant changes to the broad scale distribution of sea turtles had occurred between 1996 and 1999. As individuals, sea turtles display strong fidelity to specific feeding- and nesting-grounds (Limpus *et al.* 1994a). There are no anecdotal reports to suggest that significant changes in the relative distribution of sea turtles along the Queensland east coast have occurred over the last decade (Dr Colin Limpus, QPWS, personal communication 2002). However, this does not imply that declines in the size of some sub-populations have not altered absolute sea turtle densities. It is assumed that changes in absolute numbers of sea turtles have occurred evenly across the areas sampled by trawling effort and aerial survey.

Because sea turtle by-catch information was collected throughout the year for six years, the sea turtle CPUE encompasses seasonal differences in relative density as a consequence of migration to breeding aggregations. For this reason, season and nesting-ground status were included as factors in the GLM analysis of sea turtle CPUE. However, the aerial surveys were conducted between October and December, which coincides with the migration of sea turtles to breeding areas along the Queensland east coast. Therefore, the estimates of the relative density of sea turtles derived from the aerial survey is likely to be biased for breeding ground aggregation. However, only mature sea turtles undertake breeding migrations and only a proportion of the adult population will migrate to breed in any one year (Limpus *et al.* 1992; Limpus and Limpus 2001).

5.4 RESULTS

5.4.1 In-water sea turtle density estimated from trawl captures

Observed sea turtle CPUE for CFISH grids (30^2nm)

The sample fleet reported a total of 23,789 days of fishing at the spatial resolution of 30^2nm. However, 48 CFISH grids had <30 days of sampling effort and were excluded. Therefore, observed sea turtle CPUE was estimated for 74 CFISH grids where ≥30 days of fishing effort was recorded by the sample fleet, representing in total 23,321 days of sampling effort. Five CFISH grids along the Queensland east coast had the highest class of observed sea turtle CPUE for all species combined (Figure 5.5). As expected, observed sea turtle CPUE varied amongst areas. In general, inshore waters had higher sea turtle CPUE than offshore waters. CFISH grids with high observed sea turtle CPUE of *N. depressus* were located mostly in northern Queensland (Figure 5.6), whilst CFISH grids with high observed sea turtle CPUE of *C. mydas* were located throughout the waters of the Queensland coast (Figure 5.7). CFISH grids with a high value of observed sea turtle CPUE of *C. caretta* were located mostly in southern Queensland (Figure 5.8). Observed sea turtle CPUE of *L. olivacea* was highest in northern Queensland (Figure 5.9), whilst observed sea turtle CPUE of *E. imbricata* was low throughout Queensland (Figure 5.10). In general, this concurs with the available knowledge on the relative distribution of sea turtles in waters of the Queensland east coast, as discussed in Chapter 2, section 2.4.2.

Figure 5.5 Observed sea turtle CPUE per CFISH grid (30^2nm) for all species

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

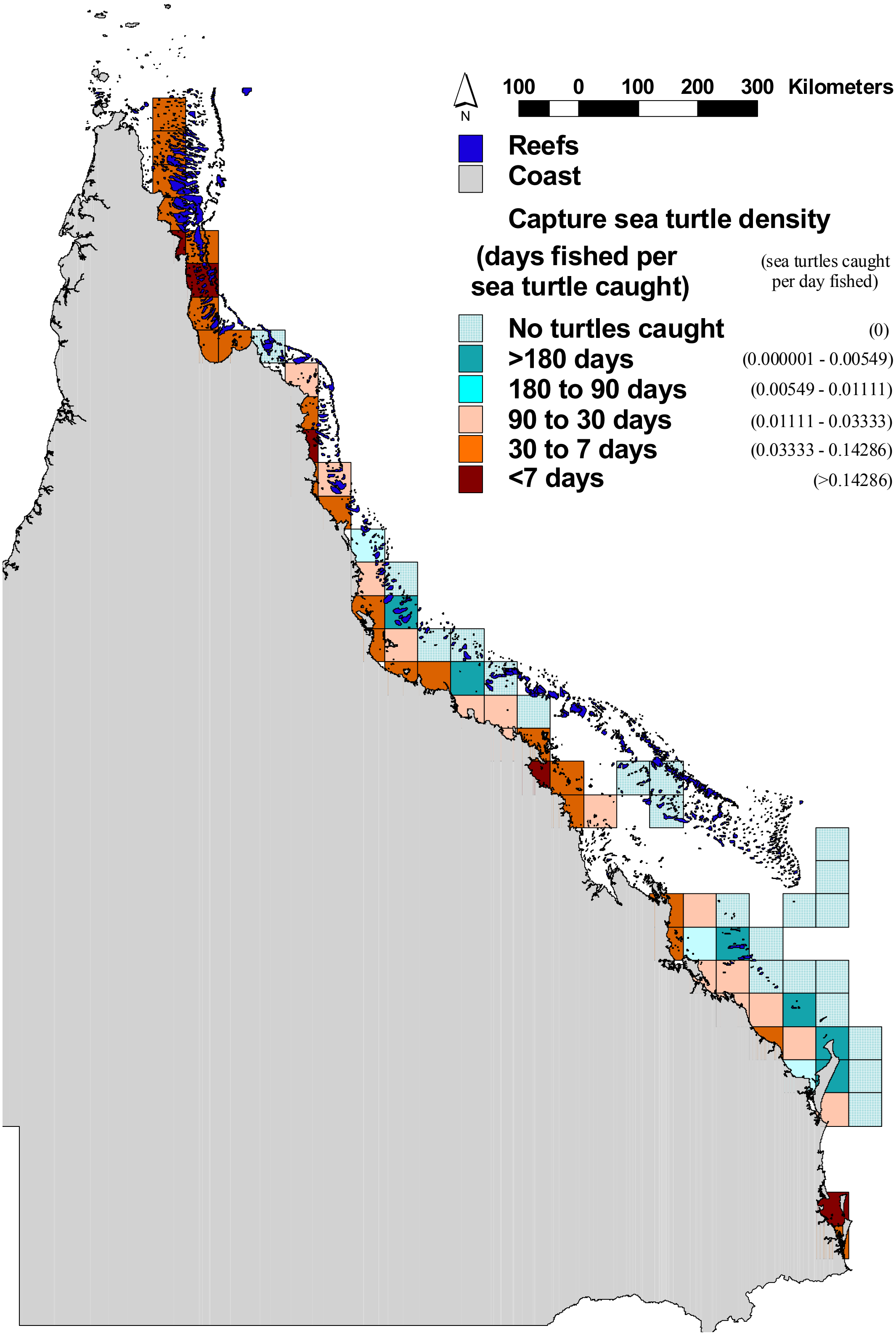


Figure 5.6 Observed sea turtle CPUE per CFISH grid (30^2nm) for *N. depressus*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

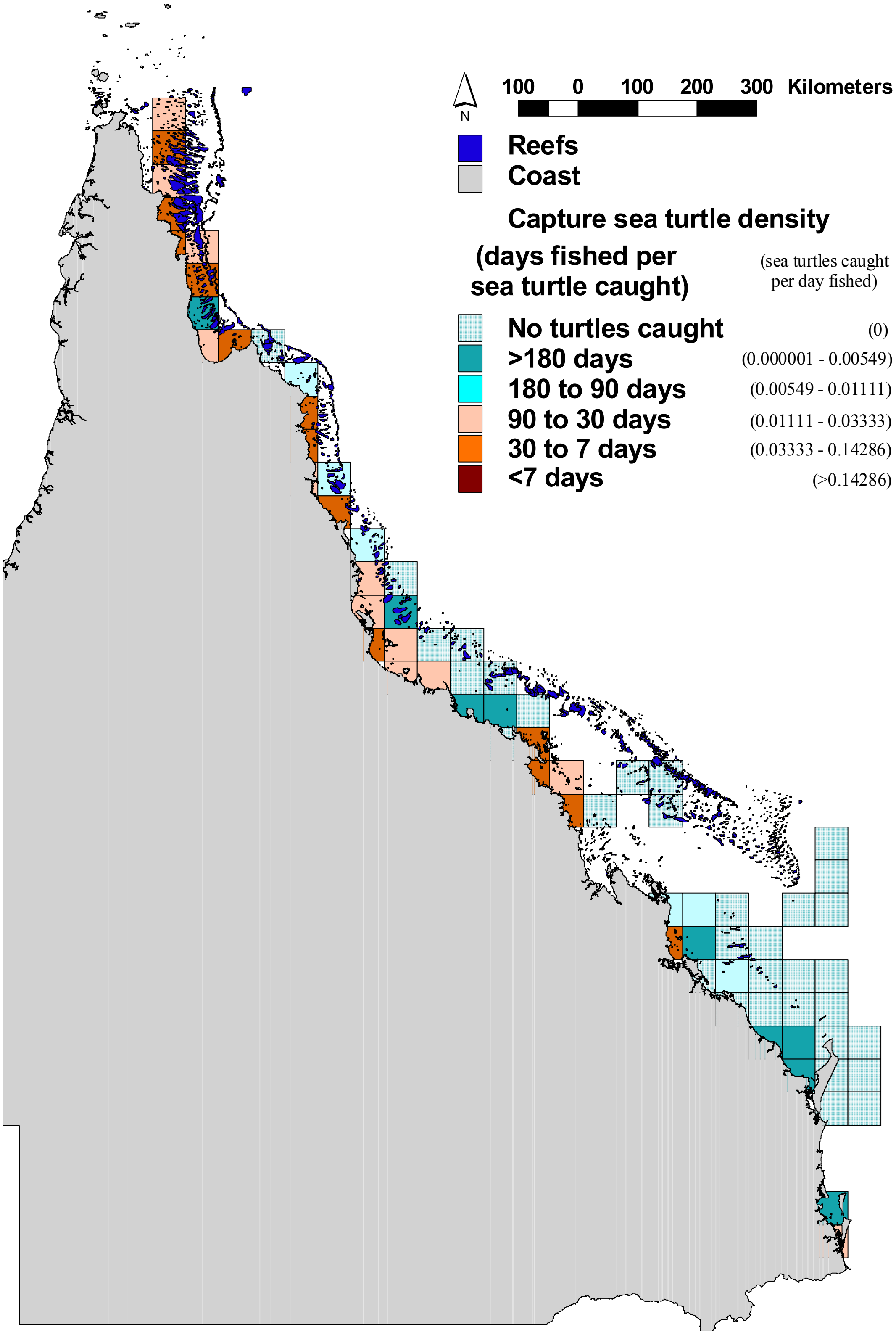


Figure 5.7 Observed sea turtle CPUE per CFISH grid (30^2nm) for *C. mydas*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

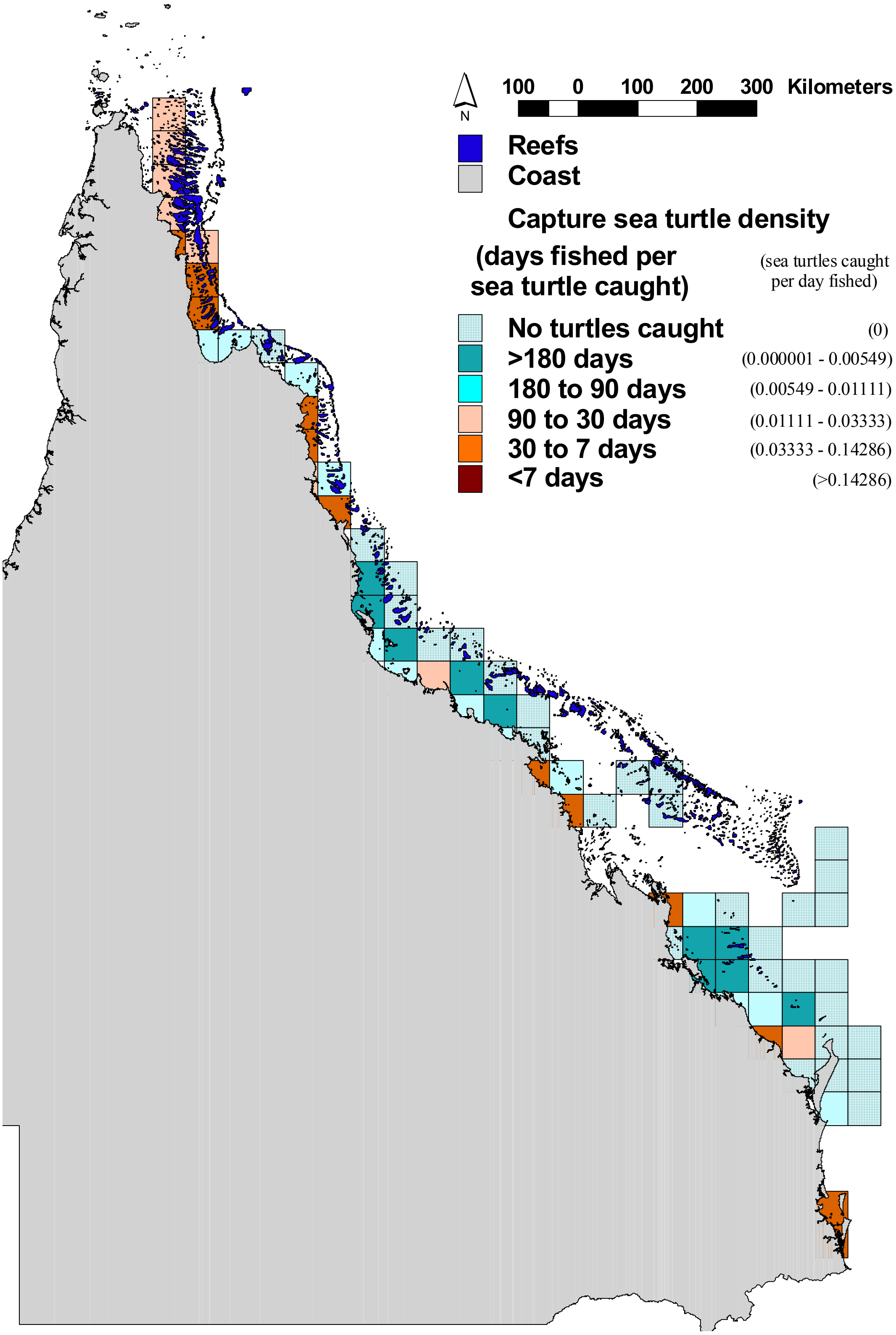


Figure 5.8 Observed sea turtle CPUE per CFISH grid (30^2nm) for *C. caretta*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

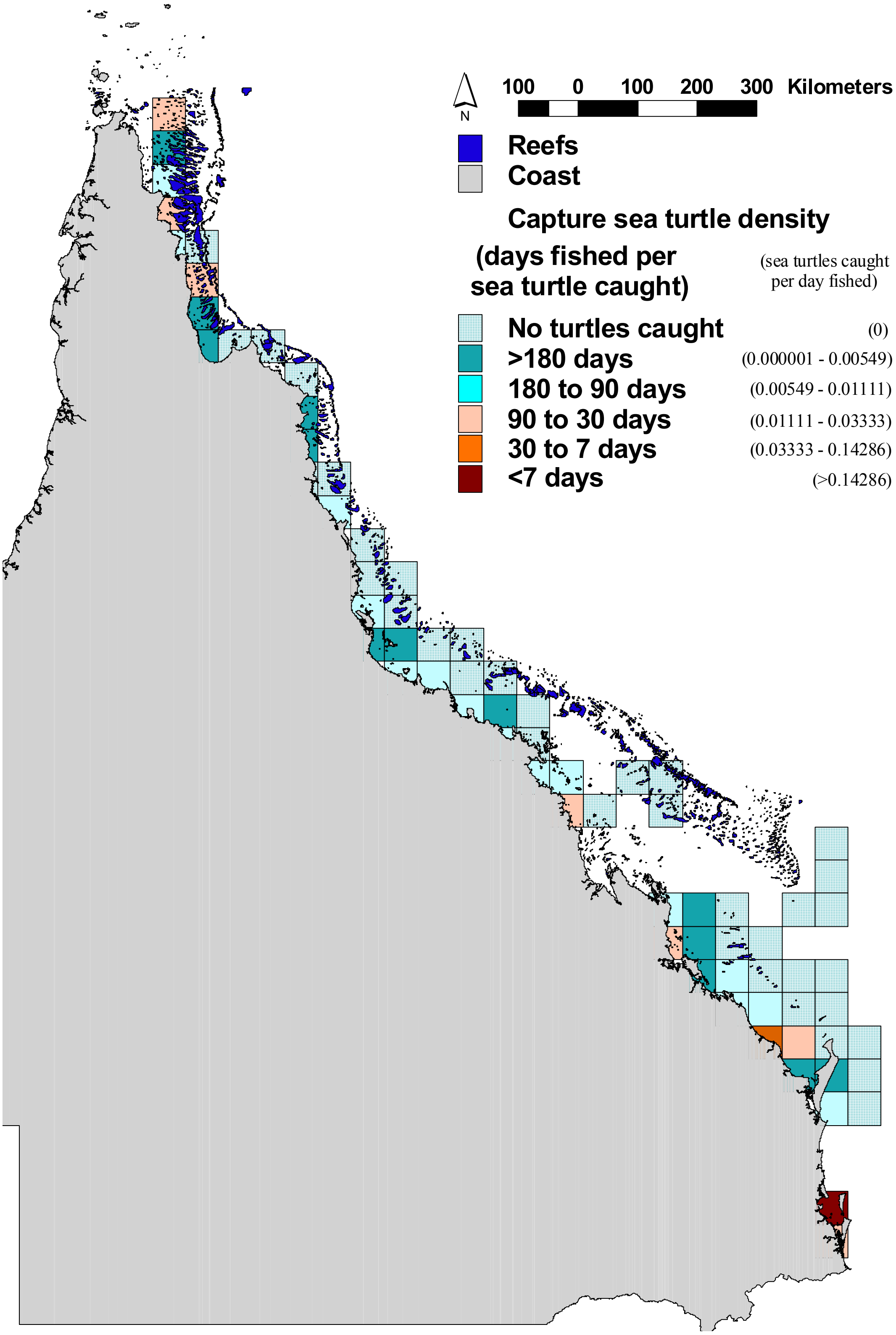


Figure 5.9 Observed sea turtle CPUE per CFISH grid (30^2nm) for *L. olivacea*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

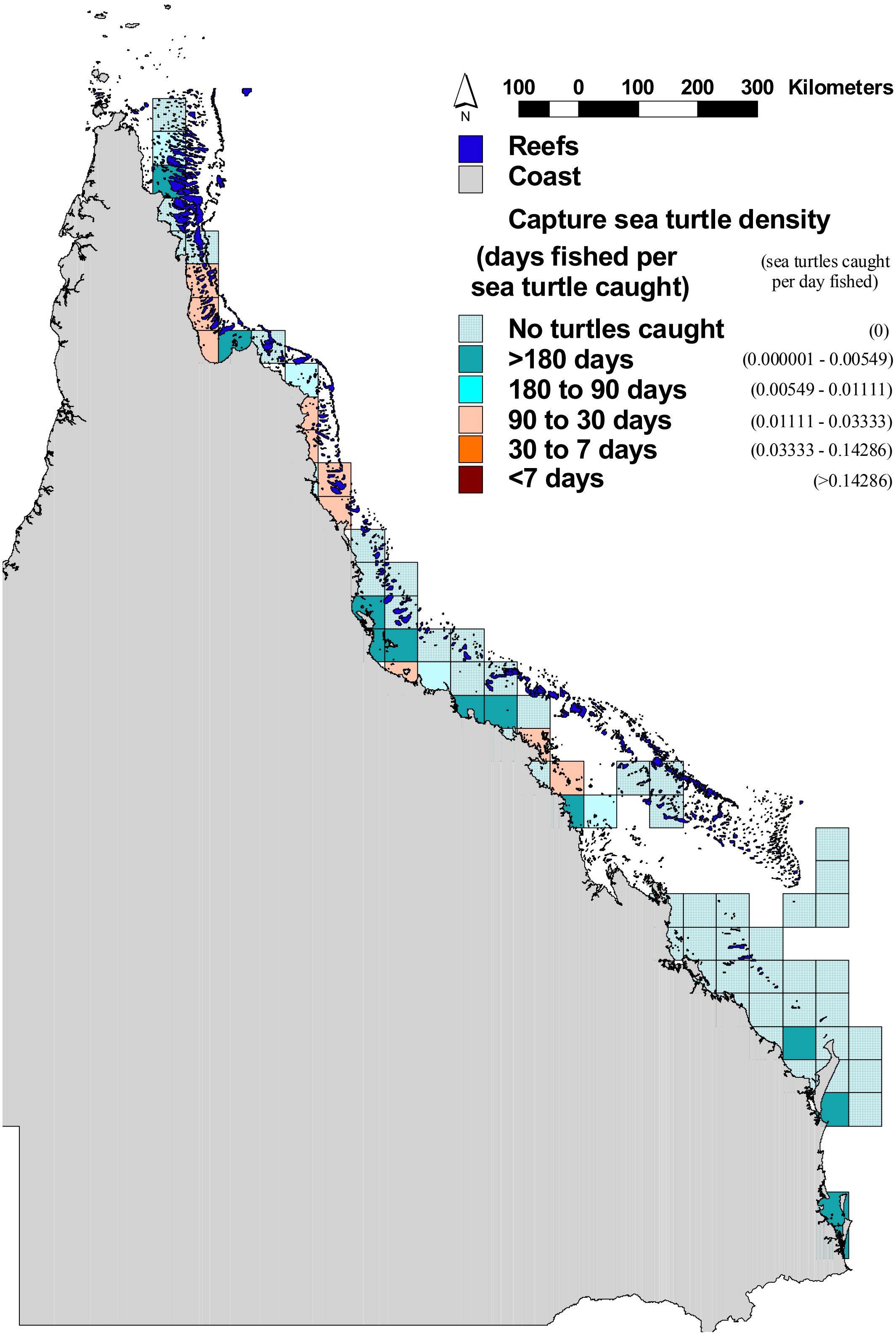
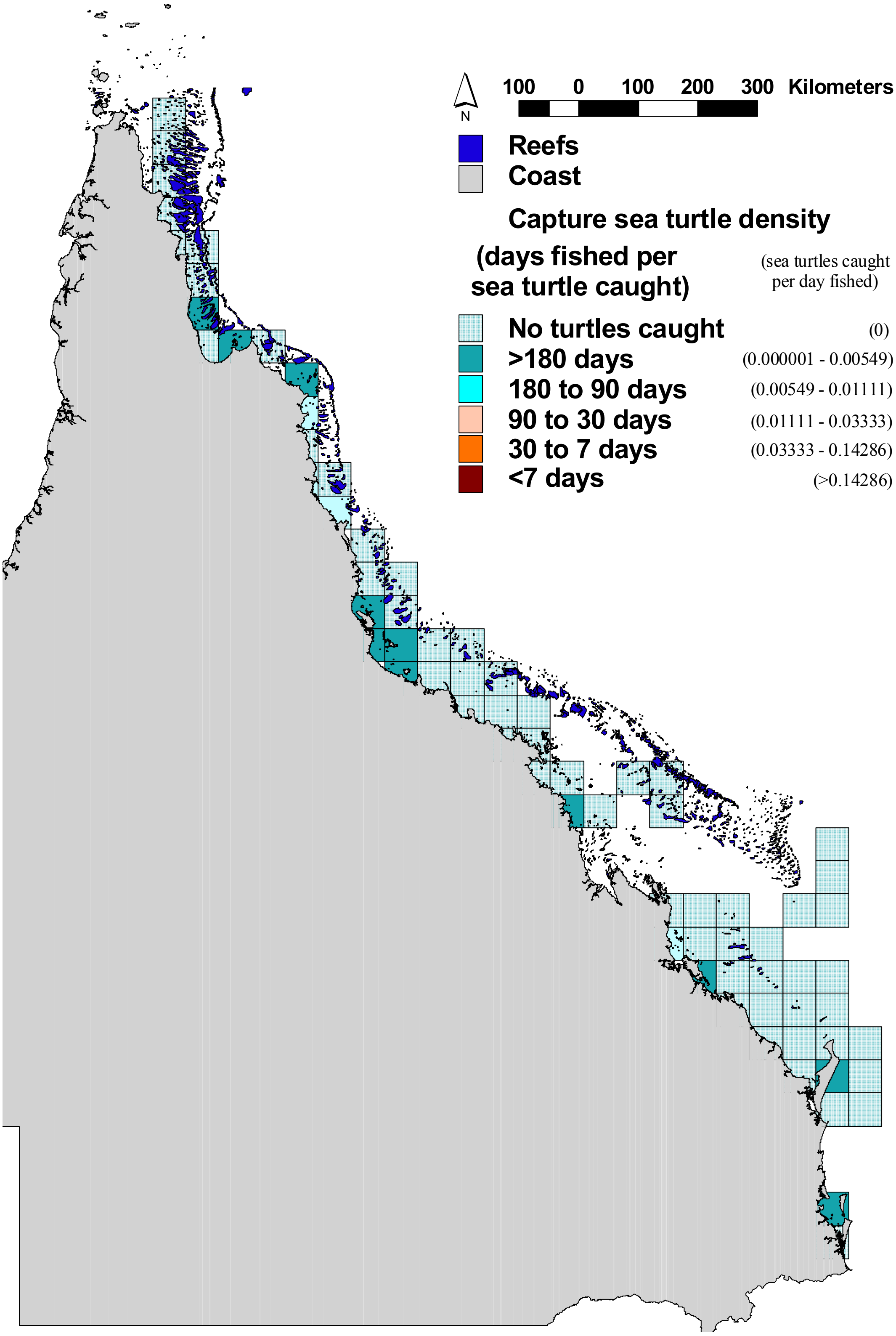


Figure 5.10 Observed sea turtle CPUE per CFISH grid (30^{2}nm) for *E. imbricata*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).



Observed sea turtle CPUE for CFISH sites (6^2nm)

The sample fleet reported a total of 8,224 days of fishing at the spatial resolution of 6^2nm. However, 591 CFISH sites had <10 days of sampling effort and were excluded. Observed sea turtle CPUE (sea turtles caught per day fished) was estimated for 234 CFISH sites where ≥10 days of fishing effort was recorded by the sample fleet, representing in total 7,989 days of sampling effort.

Despite covering a smaller total area, the observed sea turtle CPUE per CFISH site provided greater insight into which inshore areas and bays had high sea turtle density than that suggested by observed sea turtle CPUE calculated for CFISH grids (see Figure 5.11 to Figure 5.16). For example, CFISH sites near Fraser Island and Townsville had higher sea turtle CPUE per CFISH site (Figure 5.11) than sea turtle CPUE per CFISH grid (Figure 5.6).

Observed sea turtle CPUE per CFISH site varied for each species (Figures 5.12 to 5.16). In general, the patterns of distribution of observed sea turtle CPUE per CFISH site for each species was similar to the patterns of observed sea turtle CPUE per CFISH grid. For example, CFISH sites with high observed sea turtle CPUE for *N. depressus* were generally located in the tropical waters of northern Queensland (Figure 5.12), whilst CFISH sites with high observed sea turtle CPUE for *C. caretta* were generally located in sub-tropical waters of southern Queensland (Figure 5.14).

Figure 5.11 Observed sea turtle CPUE per CFISH site (6^2nm) for all species

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

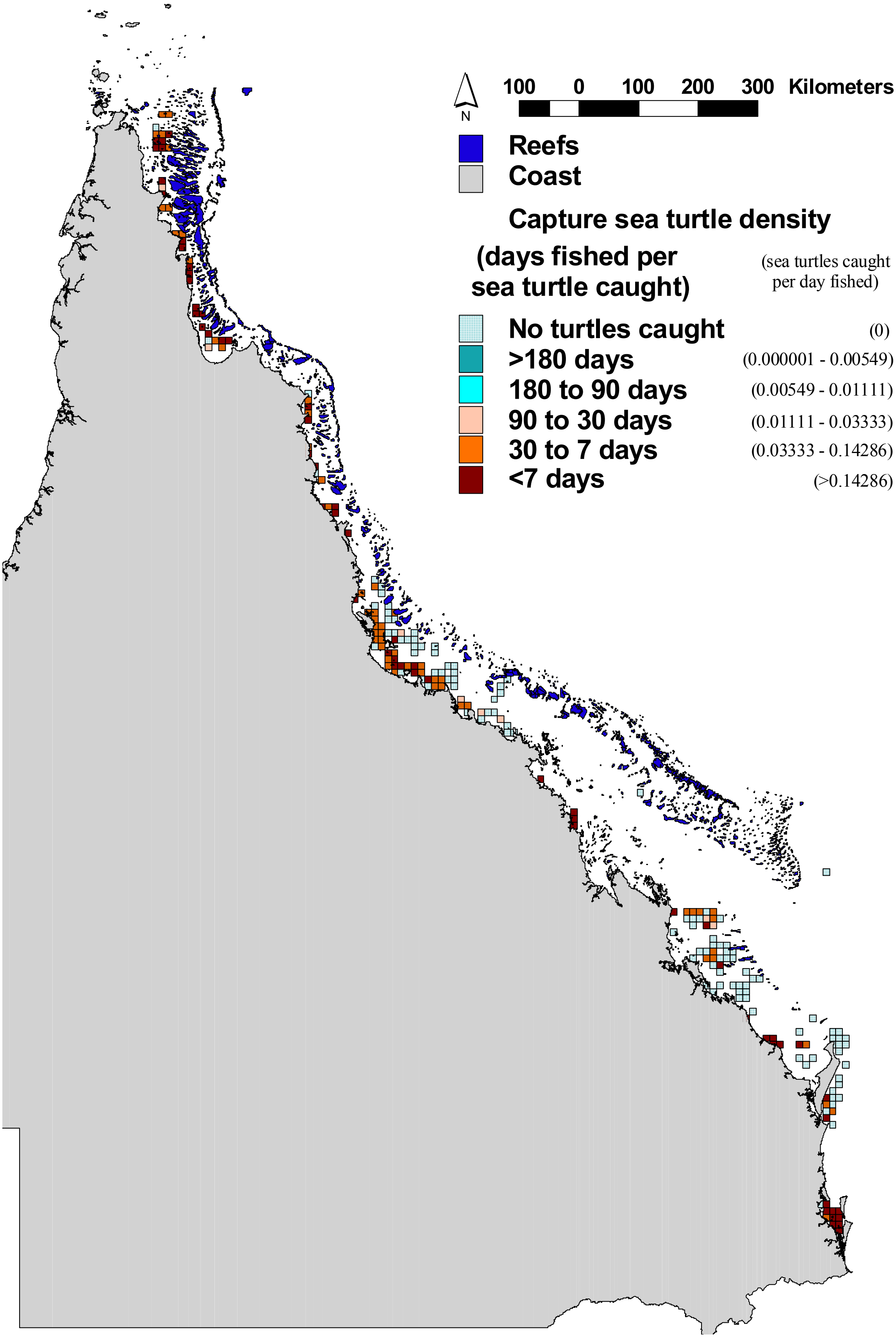


Figure 5.12 Observed sea turtle CPUE per CFISH site (6^2nm) for *N. depressus*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

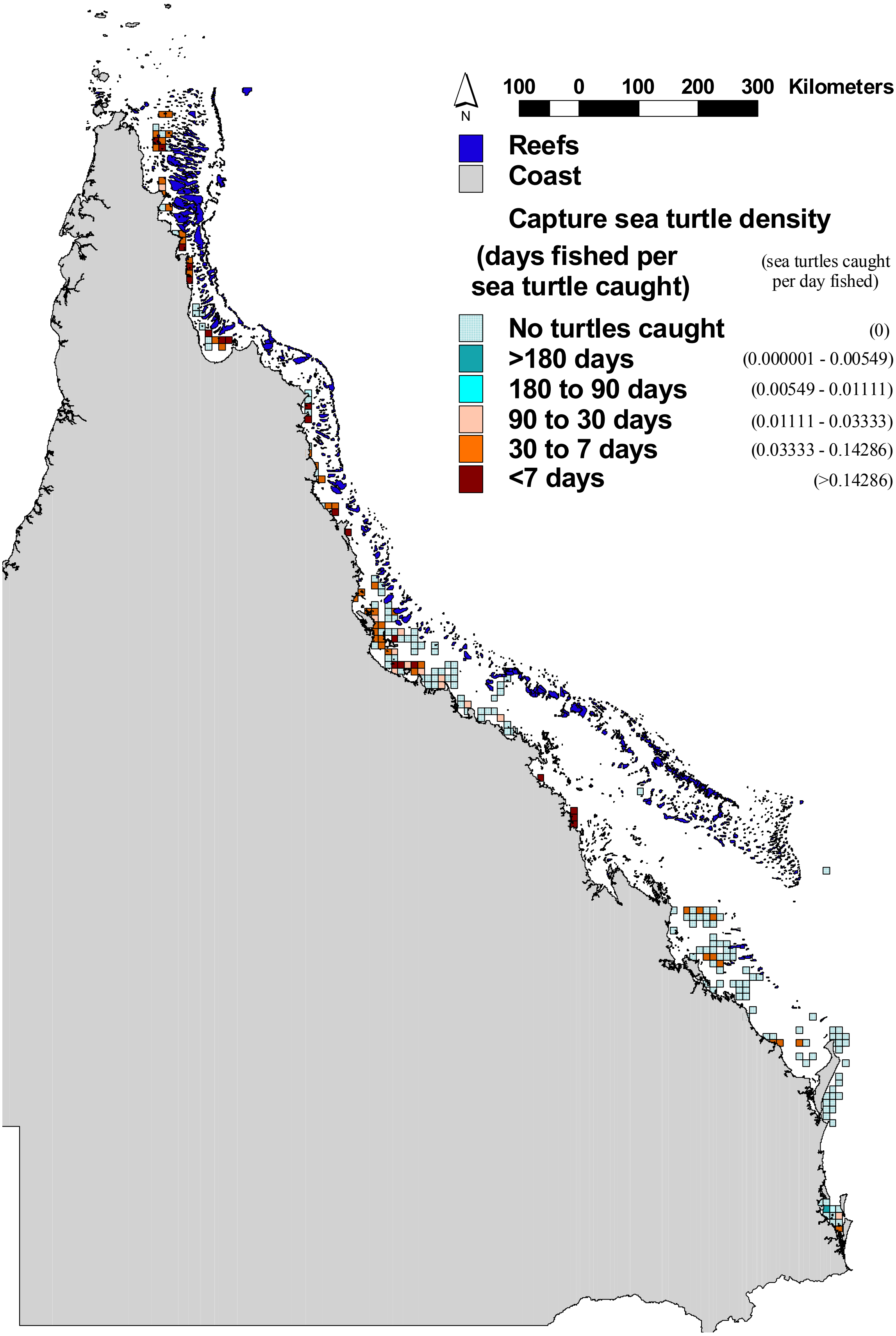


Figure 5.13 Observed sea turtle CPUE per CFISH site (6^2nm) for *C. mydas*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

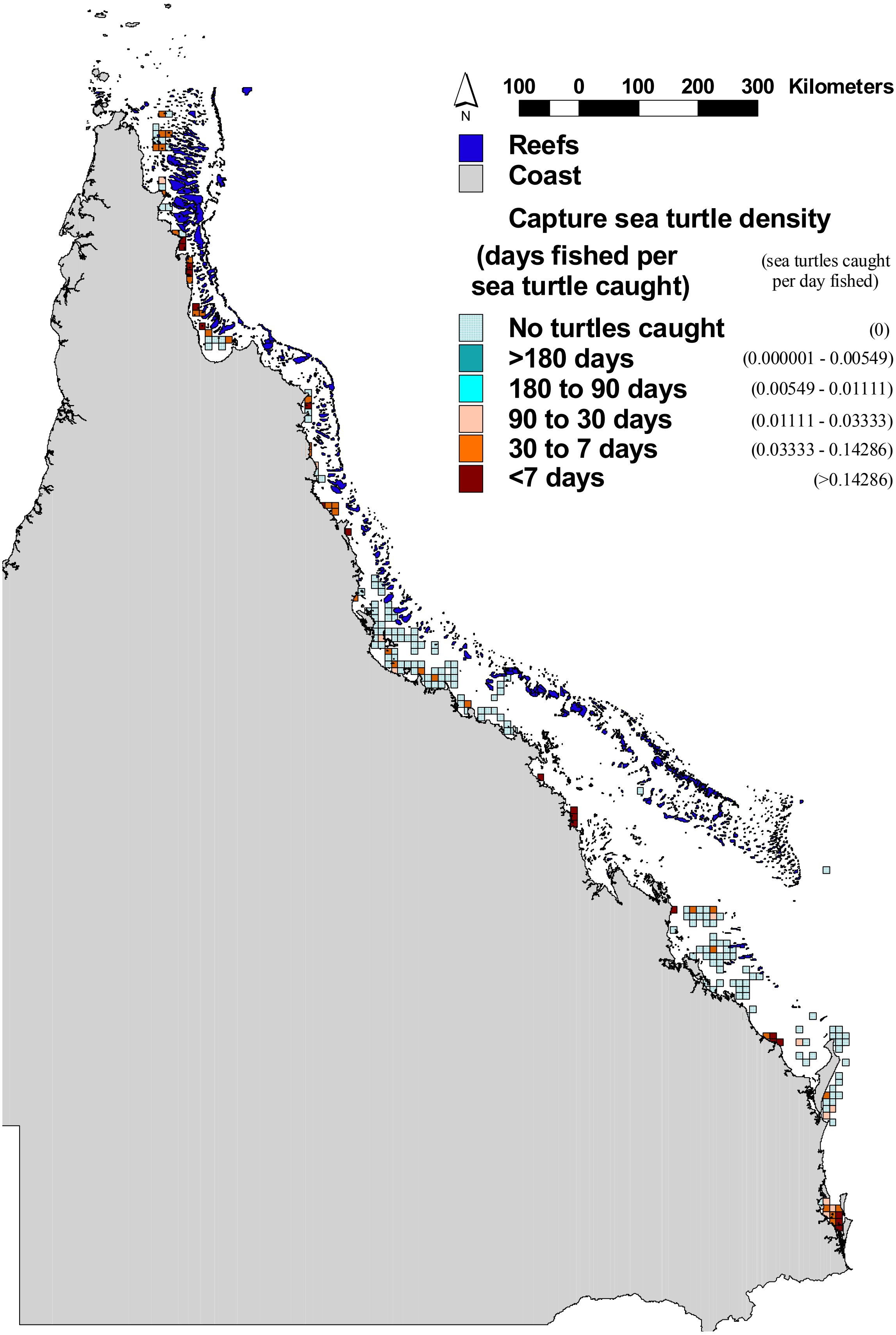


Figure 5.14 Observed sea turtle CPUE per CFISH site (6^2nm) for *C. caretta*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

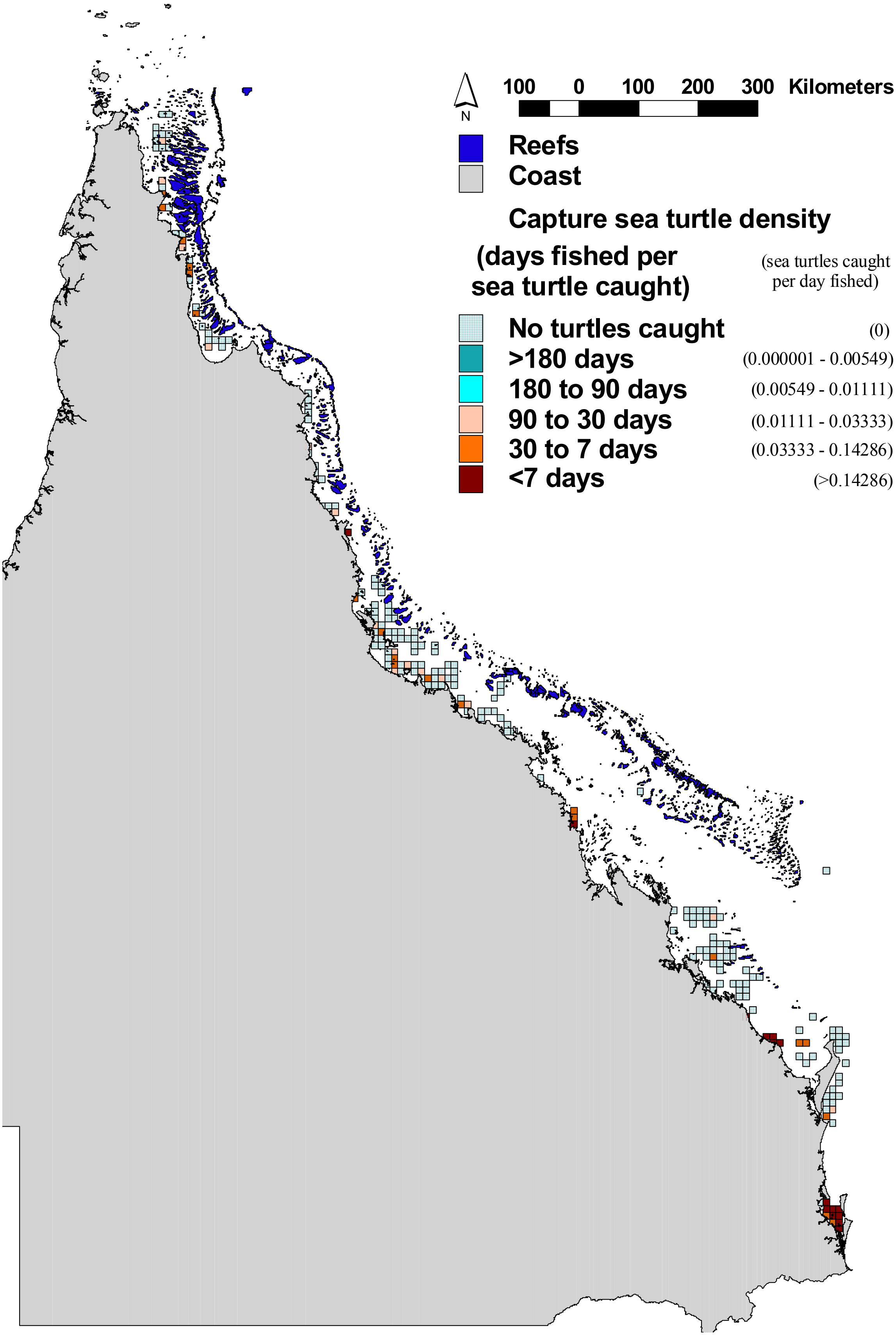


Figure 5.15 Observed sea turtle CPUE per CFISH site (6^2nm) for *L. olivacea*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

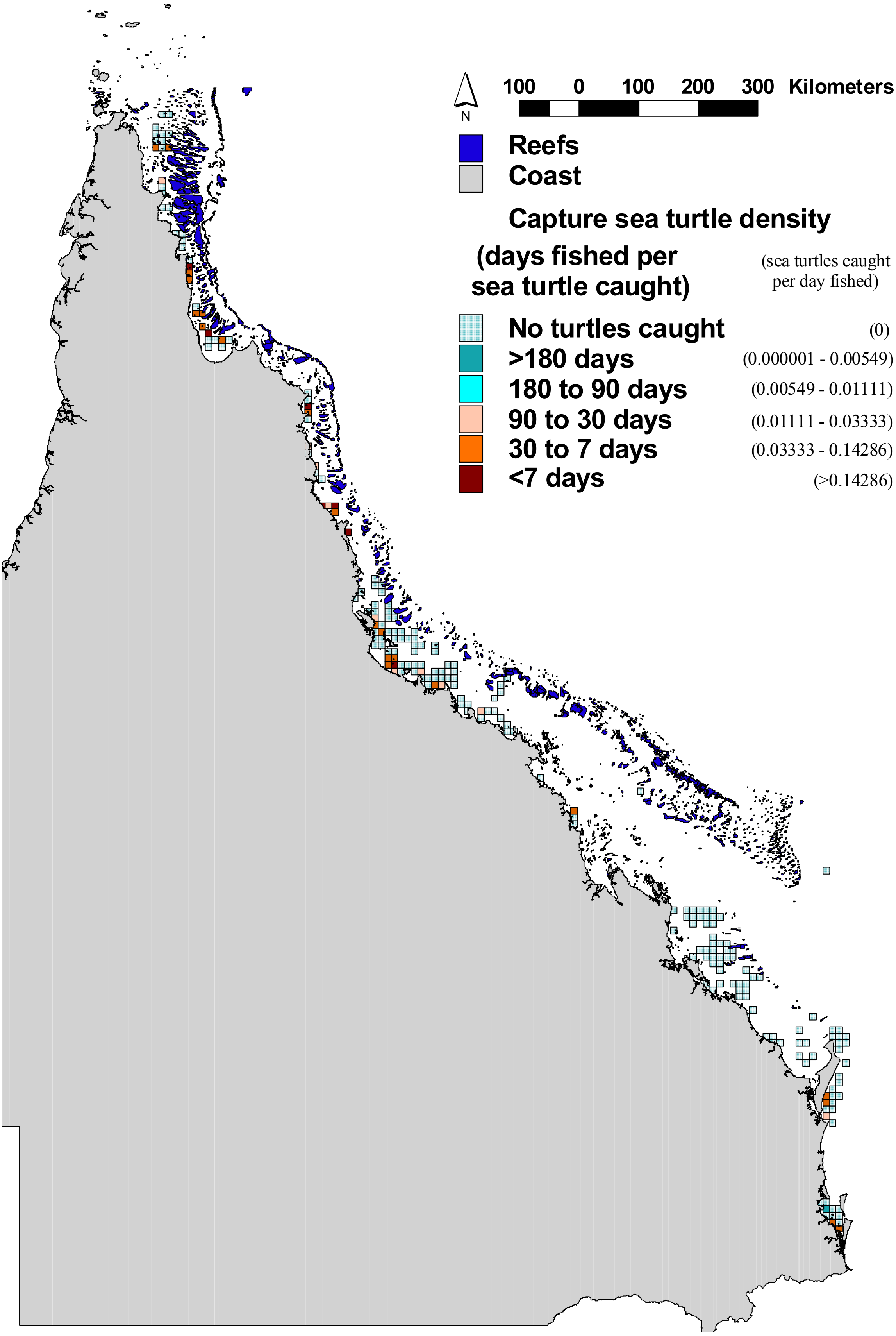
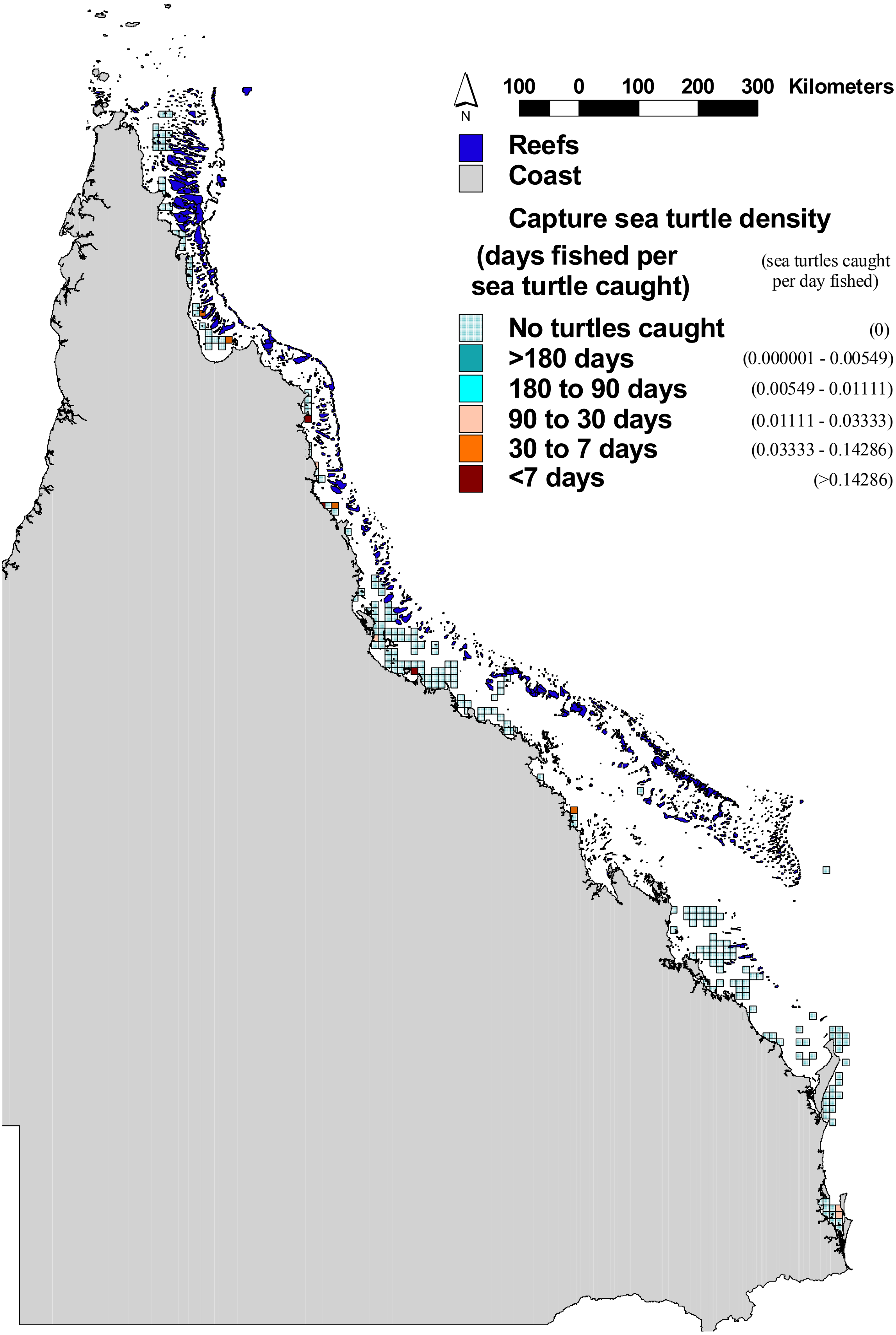


Figure 5.16 Observed sea turtle CPUE for CFISH sites (6^2nm) for *E. imbricata*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).



Predicted sea turtle CPUE for CFISH sites (6^2nm)

FACTORS INFLUENCING SEA TURTLE CATCH RATES

Ninety-five percent of sea turtles were caught from waters ≤30 m deep and no sea turtles were reported caught in waters >60 m. *C. caretta* and *C. mydas* were caught most frequently in waters ≤20 m (Table 5.3). *N. depressus, L. olivacea and E. imbricata* were caught more frequently in slightly deeper waters i.e., 11 to 30 m (Table 5.3).

Table 5.3 Frequency of sea turtle capture by depth

Water-depth (m)	*N. depressus*	*C. caretta*	*L. olivacea*	*C. mydas*	*E. imbricata*	All species
≤10	14.4%	49.4%	15.4%	40.3%	13.6%	35.8%
11-20	53.7%	39.3%	56.4%	44.6%	50.0%	45.6%
21-30	25.9%	8.6%	23.1%	10.1%	22.7%	14.2%
31-40	4.5%	2.2%	5.1%	2.4%	13.6%	3.1%
41-50	1.3%	0.0%	0.0%	1.9%	0.0%	0.9%
51-60	0.3%	0.5%	0.0%	0.7%	0.0%	0.5%

Many of the terms included in the GLM analysis were statistically significant (Table 5.4) because of the large number of degrees of freedom (d.f.). However, the order-of-magnitude of the deviance ratio (d.r.) indicated which significant terms had the greatest influence on the analysis. For all species combined (Table 5.4), fishing sector (d.r. = 468.77) was the most influential factor, with the next most influential factors being depth (d.r .= 49.49), nesting-ground status (d.r. = 45.49) and the fishing sector by depth interaction (d.r. = 32.58).

Table 5.4 Accumulated analysis of deviance of catch rates for all species

	d.f.	Deviance	Mean deviance	Deviance ratio (d.r.)	~ F prob.
Fishing sector	6	1240.8580	206.8097	468.77	<0.001
Depth	6	131.0109	21.8352	49.49	<0.001
Season	1	6.6315	6.6315	15.03	<0.001
Nesting-ground status (ngs)[A]	1	20.0695	20.0695	45.49	<0.001
Fishing sector by depth	20	287.4612	14.3731	32.58	<0.001
Fishing sector by season	6	26.1890	4.3648	9.89	<0.001
Fishing sector by ngs	5	9.4260	1.8852	4.27	<0.001
Depth by season	6	6.5768	1.0961	2.48	0.021
Depth by ngs	5	1.2701	0.2540	0.58	0.719
Season by ngs	1	2.3487	2.3487	5.32	0.021
Fishing sector by depth by season	19	25.0029	1.3159	2.98	<0.001
Fishing sector by depth by ngs	11	31.2115	2.8374	6.43	<0.001
Fishery by season by ngs	4	2.6537	0.6634	1.50	0.198
Depth by season by ngs	5	8.7818	1.7564	3.98	0.001
Fishing sector by depth by season by ngs	4	7.8770	1.9692	4.46	0.001
Residual	7889	3480.4550	0.4412		
Total	7989	5287.8235	0.6619		

[A] Nesting-ground status (ngs) for any sea turtle species.

For *N. depressus* (Table 5.5), fishing sector was an order-of-magnitude greater in its effect on the GLM analysis (d.r. = 223.86, Table 5.5) than depth (d.r. = 40.54), depth by nesting-ground status interaction (d.r. = 24.00) or season by nesting-ground status interaction (d.r. = 23.56).

Table 5.5 Accumulated analysis of deviance of catch rates of *N. depressus*

	d.f.	**Deviance**	**Mean deviance**	**Deviance ratio (d.r.)**	**~ F prob.**
Fishing sector	6	260.2976	43.3829	223.86	<0.001
Depth	6	47.1373	7.8562	40.54	<0.001
Season	1	2.2017	2.2017	11.36	<0.001
Nesting-ground status (ngs)[A]	1	1.3543	1.3543	6.99	0.008
Fishing sector by depth	20	64.5441	3.2272	16.65	<0.001
Fishing sector by season	6	13.0050	2.1675	11.18	<0.001
Fishing sector by ngs	4	8.2173	2.0543	10.60	<0.001
Depth by season	6	3.9946	0.6658	3.44	0.002
Depth by ngs	3	13.9557	4.6519	24.00	<0.001
Season by ngs	1	4.5657	4.5657	23.56	<0.001
Fishing sector by depth by season	19	10.1502	0.5342	2.76	<0.001
Fishing sector by depth by ngs	4	0.0000	0.0000	0.00	1.000
Fishing sector by season by ngs	3	5.5889	1.8630	9.61	<0.001
Depth by season by ngs	2	0.0034	0.0017	0.01	0.991
Fishing sector by depth by season by ngs	2	0.0000	0.0000	0.00	1.000
Residual	7905	1531.9640	0.1938		
Total	7989	1966.9350	0.2462		

[A] Nesting-ground status (ngs) for *N. depressus*.

For *C. mydas*, the most influential factors were fishing sector (d.r. = 197.85), depth (d.r. = 93.49), and season (d.r. = 59.31, Table 5.6).

Table 5.6 Accumulated analysis of deviance of catch rates of *C. mydas*

	d.f.	**Deviance**	**Mean deviance**	**Deviance ratio (d.r.)**	**~ F prob.**
Fishing sector	6	260.2874	43.3812	197.85	<0.001
Depth	6	122.9897	20.4983	93.49	<0.001
Season	1	13.0053	13.0053	59.31	<0.001
Nesting ground status (ngs)[A]	1	1.6162	1.6162	7.37	0.007
Fishing sector by depth	20	75.1566	3.7578	17.14	<0.001
Fishing sector by season	6	5.7108	0.9518	4.34	<0.001
Fishing sector by ngs	5	12.6336	11.52	2.53	<0.001
Depth by season	6	4.7567	0.7928	3.62	0.001
Depth by ngs	5	6.0607	1.2121	5.53	<0.001
Season by ngs	1	2.1811	2.1811	9.95	0.002
Fishing sector by depth by season	19	17.3998	0.9158	4.18	<0.001
Fishing sector by depth by ngs	11	14.3048	1.3004	5.93	<0.001
Fishing sector by season by ngs	4	4.5064	1.1266	5.14	<0.001
Depth by season by ngs	5	5.6698	1.1340	5.17	<0.001
Fishing sector by depth by season by ngs	4	0.0002	0.0001	0.00	1.000
Residual	7889	1729.7962	0.2193		
Total	7989	2276.0753	0.2849		

[A] Nesting-ground status (ngs) for *C. mydas*.

For *C. caretta*, fishing sector (d.r. = 995.47) was the most influential factor, followed by nesting-ground status (d.r. = 180.51), depth (d.r. = 53.39) and the season by nesting-ground status interaction (d.r. = 51.31, Table 5.7).

Table 5.7 Accumulated analysis of deviance of catch rates of *C. caretta*

	d.f.	**Deviance**	**Mean deviance**	**Deviance ratio (d.r.)**	**~ F prob.**
Fishing sector	6	1112.7701	185.4617	995.47	<0.001
Depth	6	59.6862	9.9477	53.39	<0.001
Season	1	0.0531	0.0531	0.28	0.594
Nesting-ground status (ngs)[A]	1	33.6305	33.6305	180.51	<0.001
Fishing sector by depth	20	75.7792	3.7890	20.34	<0.001
Fishing sector by season	6	22.5992	3.7665	20.22	<0.001
Fishing sector by ngs	4	11.0547	2.7637	14.83	<0.001
Depth by season	6	6.1201	1.0200	5.47	<0.001
Depth by ngs	5	4.6746	0.9349	5.02	<0.001
Season by ngs	1	9.5592	9.5592	51.31	<0.001
Fishing sector by depth by season	19	10.2423	0.5391	2.89	<0.001
Fishing sector by depth by ngs	6	0.3223	0.0537	0.29	0.943
Fishing sector by season by ngs	4	2.5345	0.6336	3.40	0.009
Depth by season by ngs	4	1.2820	0.3205	1.72	0.142
Fishing sector by depth by season by ngs	2	0.0001	0.0000	0.00	1.000
Residual	7898	1471.4449	0.1863		
Total	7989	2821.7529	0.3532		

[A] Nesting-ground status (ngs) for *C. caretta*.

No significant nesting-grounds of *L. olivacea* have been recorded along the Queensland east coast, so the analysis of catches of *L. olivacea* used the factors fishing sector, depth and season, of which fishing sector (d.r. = 113.92) and depth (d.r. = 84.65) were the most influential factors (Table 5.8).

Table 5.8 Accumulated analysis of deviance of catch rates for *L. olivacea*

	d.f.	**Deviance**	**Mean deviance**	**Deviance ratio (d.f.)**	**~ F prob.**
Fishing sector	6	46.09202	7.68200	113.92	<0.001
Depth	6	34.24975	5.70829	84.65	<0.001
Season	1	0.32368	0.32368	4.80	0.028
Fishing sector by depth	20	16.16055	0.80803	11.98	<0.001
Fishing sector by season	6	12.59706	2.09951	31.13	<0.001
Depth by season	6	0.56652	0.09442	1.40	0.210
Fishing sector by depth by season	19	14.11480	0.74288	11.02	<0.001
Residual	7925	534.42205	0.06743		
Total	7989	658.52644	0.08243		

The full model could not be fitted to the daily catch data for *E. imbricata* because of the high proportion of days with zero captures. The maximal model that could be fitted is presented in Table 5.9. The factors with the greatest influence in the analysis were the fishing sector by nesting-ground status interaction (d.r. = 130.97) and fishing sector (d.r. = 115.16, Table 5.9).

Table 5.9 Accumulated analysis of deviance of catch rates for *E. imbricata*

	d.f.	Deviance	Mean deviance	Deviance ratio	~ F prob.
Fishing sector	6	15.56946	2.59491	115.16	<0.001
Depth	6	3.67970	0.61328	27.22	<0.001
Season	1	0.67421	0.67421	29.92	<0.001
Nesting-ground status (ngs)[A]	1	0.82519	0.82519	36.62	<0.001
Fishing sector by depth	20	11.55591	0.57780	25.64	<0.001
Fishing sector by season	6	6.51117	1.08519	48.16	<0.001
Fishing sector by ngs	2	5.90277	2.95139	130.97	<0.001
Depth by season	6	6.50000	1.08333	48.08	<0.001
Depth by ngs	2	0.00078	0.00039	0.02	0.983
Season by ngs	1	0.00012	0.00012	0.01	0.943
Fishing sector by depth by season	19	0.00117	0.00006	0.00	1.000
Fishing sector by depth by ngs	3	0.00000	0.00000	0.00	1.000
Fishing sector by season by ngs	1	0.00000	0.00000	0.00	0.998
Residual	7915	178.35678	0.02253		
Total	7989	229.57727	0.02874		

[A] Nesting-ground status (ngs) for *E. imbricata*.

Overall, the results of the GLM analysis suggested that fishing sector and water-depth were the main factors influencing the catch rates of sea turtles for all species and each individual species except *E. imbricata.* This was not unexpected because *E. imbricata* is generally associated with reef habitats that are poorly sampled by trawling. Mean sea turtle CPUEs (with their associated standard errors (s.e.)) were available from the full GLM model, but were estimated for the simple combination of seven fishing sectors by seven water-depths (Table 5.10). The full model combination of seven fishing sectors by seven water-depths by two seasons by two classes of nesting-ground status (i.e., 196 estimates of sea turtle CPUE) was not used further in predicting mean sea turtle CPUE per CFISH site because of low sampling effort in the some of combinations of all four factors. Therefore, estimated mean sea turtle CPUE was averaged for nesting-ground status and season, despite these factors often being significant in the GLM analysis.

Table 5.10 Mean sea turtle CPUE (sea turtles caught per day fished) estimated from the GLM for the combination of fishing sector and depth

Water-depth (m)		Fishing Sector of the Queensland East Coast Trawl Fishery (as determined by the main target species caught)													
		Tiger prawns		**Endeavour prawns**		**Banana prawns**		**Red spot king prawns**		**Eastern king prawns**		**Scallops**		**Moreton Bay**	
		Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
All species	0-10	0.709601	0.076515	0.698176	0.216394	0.734368	0.062629	*	*	*	*	*	*	0.429385	0.017155
	11-20	0.170732	0.008722	0.213988	0.216394	0.352505	0.024933	0.436540	0.067993	0.731757	0.252687	0.079005	0.022203	0.911040	0.057191
	21-30	0.075144	0.006734	0.114224	0.010117	0.106551	0.040852	0.058430	0.012965	0.030342	0.009019	0.079005	0.008046	1.453462	0.141726
	31-40	0.099454	0.022144	0.419021	0.145767	0.063577	0.042215	0.048703	0.021917	0.015540	0.005955	0.010406	0.003051	*	*
	41-50	0.052632	0.024719	*	*	*	*	0.003385	0.002241	0.006509	0.002486	0.021477	0.005554	*	*
	51-60	*	*	*	*	*	*	0.005501	0.003685	0.000062	0.000666	0.011924	0.004565	*	*
	>60	*	*	*	*	*	*	*	*	0.000062	0.000221	0.000062	0.000917	*	*
N. depressus	0-10	0.33172	0.033206	0.39173	0.103230	0.07147	0.010692	*	*	*	*	*	*	0.00585	0.001328
	11-20	0.06229	0.003499	0.07959	0.008692	0.15193	0.011034	0.15121	0.025154	0.00002	0.000545	0.00002	0.000341	0.01382	0.004826
	21-30	0.03831	0.003054	0.06707	0.005017	0.00002	0.000214	0.03090	0.006081	0.00599	0.002641	0.01436	0.003467	0.00002	0.000223
	31-40	0.06175	0.012183	0.14989	0.056848	0.06356	0.027979	0.00406	0.001262	0.00002	0.000125	0.00476	0.001398	*	*
	41-50	0.00002	0.000206	*	*	*	*	0.00002	0.000095	0.00217	0.000951	0.00682	0.001948	*	*
	51-60	*	*	*	*	*	*	0.00002	0.000244	0.00002	0.000177	0.00398	0.001747	*	*
	>60	*	*	*	*	*	*	*	*	0.00002	0.000086	0.00002	0.000369	*	*
C. mydas	0-10	0.23813	0.032575	0.33314	0.107614	0.34288	0.029585	*	*	*	*	*	*	0.111501	0.005995
	11-20	0.06359	0.003784	0.08211	0.009276	0.08478	0.009391	0.12888	0.023765	0.06519	0.018571	0.05012	0.012132	0.103787	0.014341
	21-30	0.02541	0.003203	0.02633	0.003596	0.00001	0.000140	0.00631	0.002950	0.00607	0.002842	0.00001	0.000052	0.152414	0.032143
	31-40	0.00001	0.000090	0.20951	0.072666	0.00001	0.000188	0.00642	0.001747	0.00001	0.000099	0.00080	0.000374	*	*
	41-50	0.05263	0.017427	*	*	*	*	0.00337	0.001575	0.00432	0.001429	0.01322	0.003253	*	*
	51-60	*	*	*	*	*	*	0.00001	0.000157	0.00001	0.000173	0.00793	0.002624	*	*
	>60	*	*	*	*	*	*	*	*	0.00001	0.000057	0.00001	0.000238	*	*

* No estimate as the combination was not present in original data.

Table 5.10 continued

	Water-	Fishing Sector of the Queensland East Coast Trawl Fishery (as determined by the main target species caught)													
	depth	**Tiger prawns**		**Endeavour prawns**		**Banana prawns**		**Red spot king prawns**		**Eastern king prawns**		**Scallops**		**Moreton Bay**	
	(m)	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
C. caretta	0-10	0.06908	0.013335	0.00410	0.001789	0.23903	0.025036	*	*	*	*	*	*	0.28313	0.009132
	11-20	0.02462	0.003569	0.01783	0.004011	0.08368	0.007725	0.06383	0.01668	0.09112	0.038469	0.01782	0.007694	0.61711	0.029921
	21-30	0.00595	0.001200	0.00653	0.001640	0.04604	0.014050	0.00785	0.00339	0.00613	0.002648	0.00923	0.002551	0.97019	0.075646
	31-40	0.01135	0.004899	0.02246	0.009695	0.00001	0.000173	0.00258	0.00111	0.01596	0.003978	0.00396	0.001368	*	*
	41-50	0.00001	0.000123	*	*	*	*	0.00001	0.00006	0.00001	0.000042	0.00001	0.000042	*	*
	51-60	*	*	*	*	*	*	0.00548	0.00237	0.00001	0.000164	0.00001	0.000069	*	*
	>60	*	*	*	*	*	*	*	*	0.00001	0.000051	0.00001	0.000219	*	*
L. olivacea	0-10	0.02763	0.005074	0.10593	0.027507	0.03844	0.005263	*	*	*	*	*	*	0.00329	0.000492
	11-20	0.01900	0.005074	0.01972	0.001707	0.00801	0.001201	0.03780	0.007419	0.09112	0.016731	0.00000	0.000062	0.00000	0.000025
	21-30	0.00721	0.000708	0.01013	0.001188	0.02192	0.005691	0.00618	0.001604	0.01195	0.002195	0.00521	0.001353	0.00000	0.000048
	31-40	0.02270	0.004168	0.02278	0.005916	0.00000	0.000063	0.00203	0.000526	0.00000	0.000027	0.00000	0.000013	*	*
	41-50	0.00000	0.000045	*	*	*	*	0.00000	0.000021	0.00000	0.000015	0.00000	0.000015	*	*
	51-60	*	*	*	*	*	*	0.00000	0.000053	0.00000	0.000038	0.00000	0.000025	*	*
	>60	*	*	*	*	*	*	*	*	0.00000	0.000019	0.00000	0.000080	*	*
E. imbricata	0-10	0.00000	0.000008	0.00000	0.000019	0.01550	0.001645	*	*	*	*	*	*	0.00000	0.000002
	11-20	0.00525	0.000347	0.00722	0.001084	0.00267	0.000401	0.00000	0.000008	0.00000	0.000023	0.00000	0.000013	0.01383	0.001645
	21-30	0.00211	0.000224	0.00388	0.000412	0.00000	0.000008	0.00170	0.000264	0.00000	0.000011	0.00000	0.000004	0.00000	0.001645
	31-40	0.00000	0.000006	0.00000	0.000018	0.00000	0.000013	0.00170	0.000426	0.00000	0.000006	0.00000	0.000003	*	*
	41-50	0.00000	0.000010	*	*	*	*	0.00000	0.000004	0.00000	0.000003	0.00000	0.000003	*	*
	51-60	*	*	*	*	*	*	0.00000	0.000011	0.00000	0.000008	0.00000	0.000005	*	*
	>60	*	*	*	*	*	*	*	*	0.00000	0.000004	0.00000	0.000017	*	*

* No estimate as the combination was not present in original data.

PREDICTING SEA TURTLE CPUE BASED ON FISHING SECTOR AND MEAN WATER-DEPTH

Fishing sector and mean water-depth (Figure 5.2 and 5.1 respectively) were used to spatially allocate the predicted mean sea turtle CPUE for each CFISH site, as estimated from the GLM. The resulting spatial distributions of predicted sea turtle CPUE per CFISH site provided better spatial resolution than observed sea turtle CPUE per CFISH grid as well as greater spatial coverage than observed sea turtle CPUE per CFISH site. The spatial distribution of predicted sea turtle CPUE suggested that the relative density of sea turtles, as sampled by trawl captures, was high in bays and shallow areas (see Figures 5.17 to 5.22). Predicted sea turtle CPUE was also high throughout the reef-shoal complexes of northern Queensland, where the continental shelf is relatively narrow.

Figure 5.17 Predicted sea turtle CPUE per CFISH site (6^2nm) for all species

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

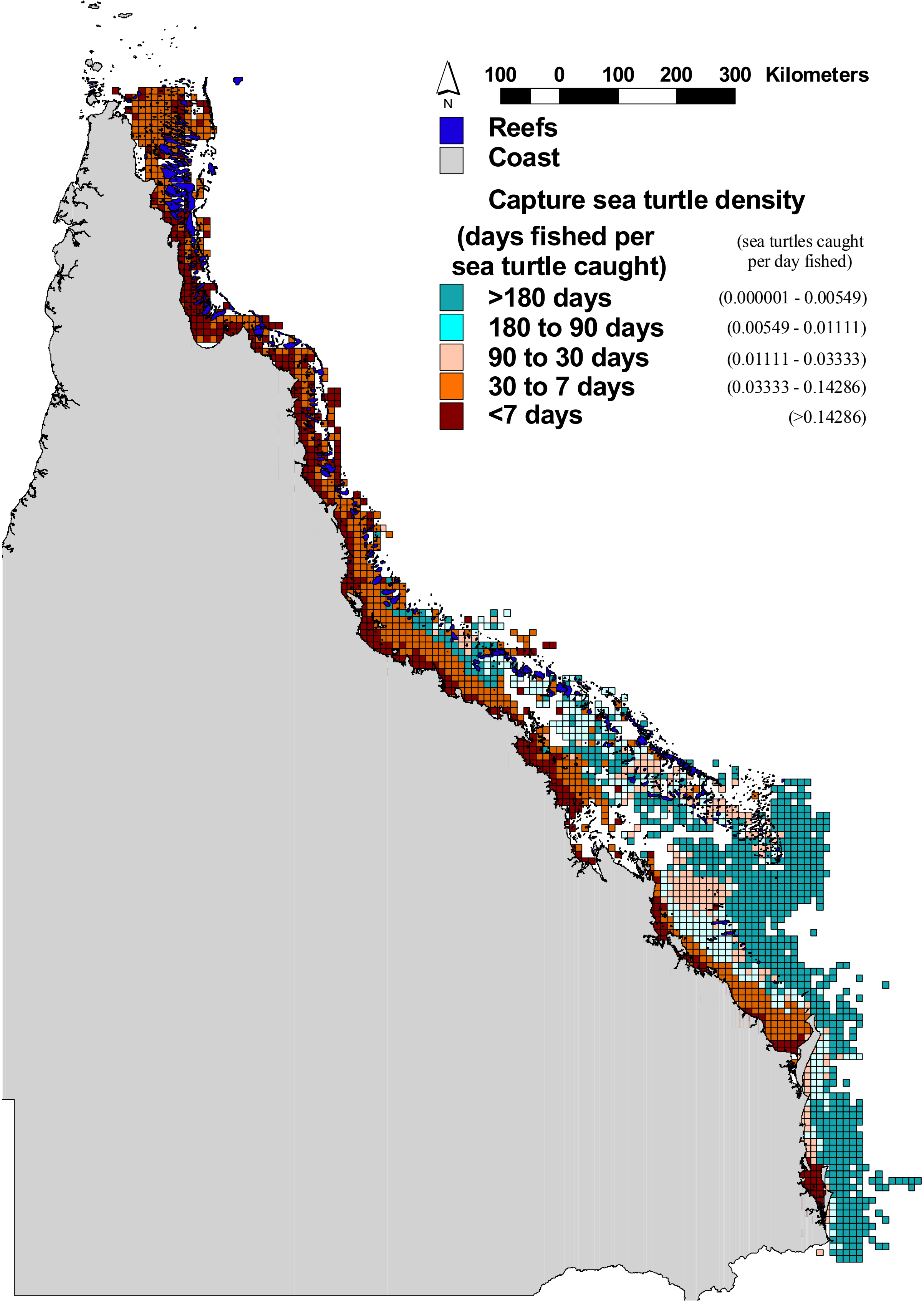


Figure 5.18 Predicted sea turtle CPUE per CFISH site (6^2nm) for *N. depressus*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

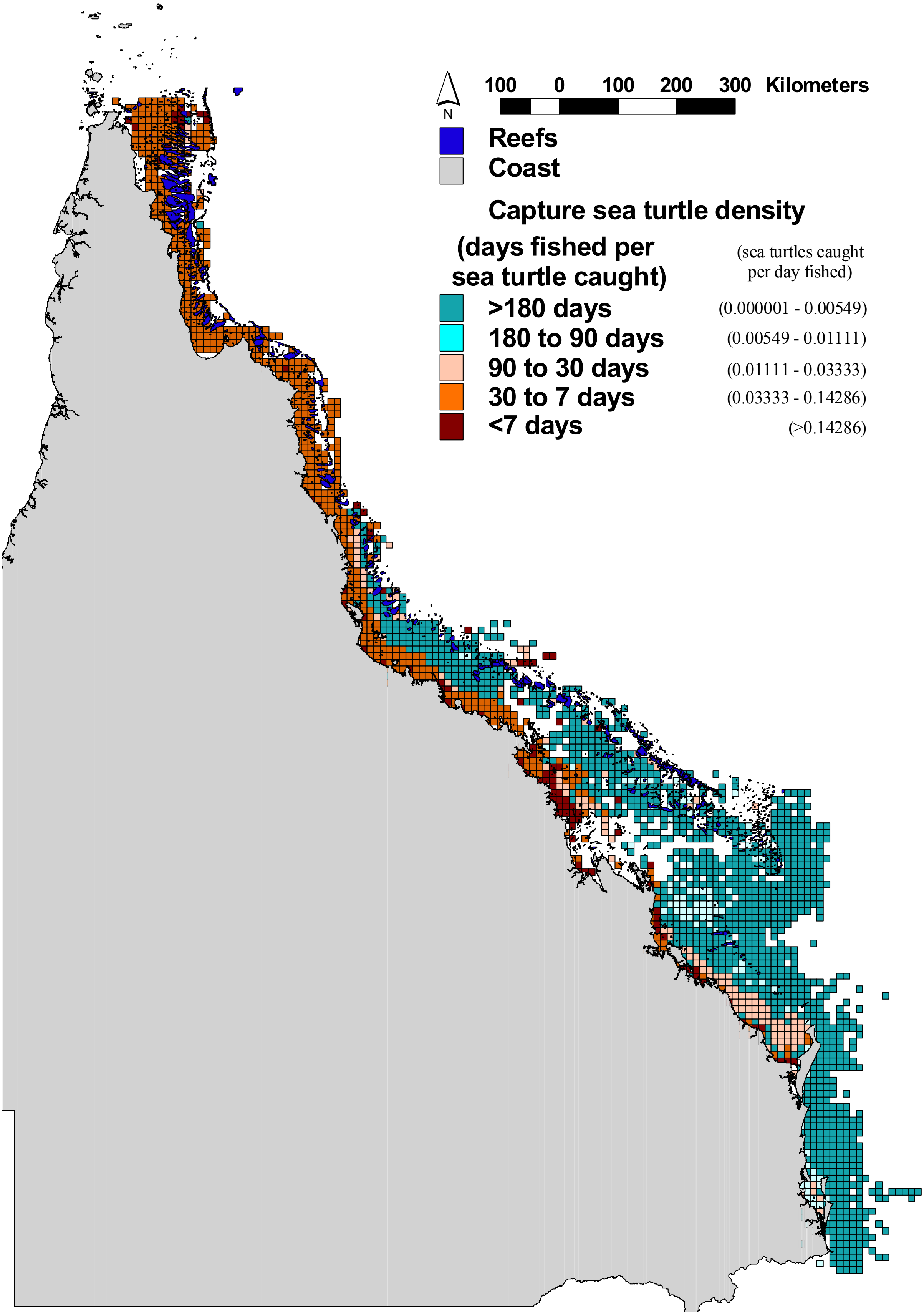


Figure 5.19 Predicted sea turtle CPUE per CFISH site (6^2nm) for *C. mydas*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

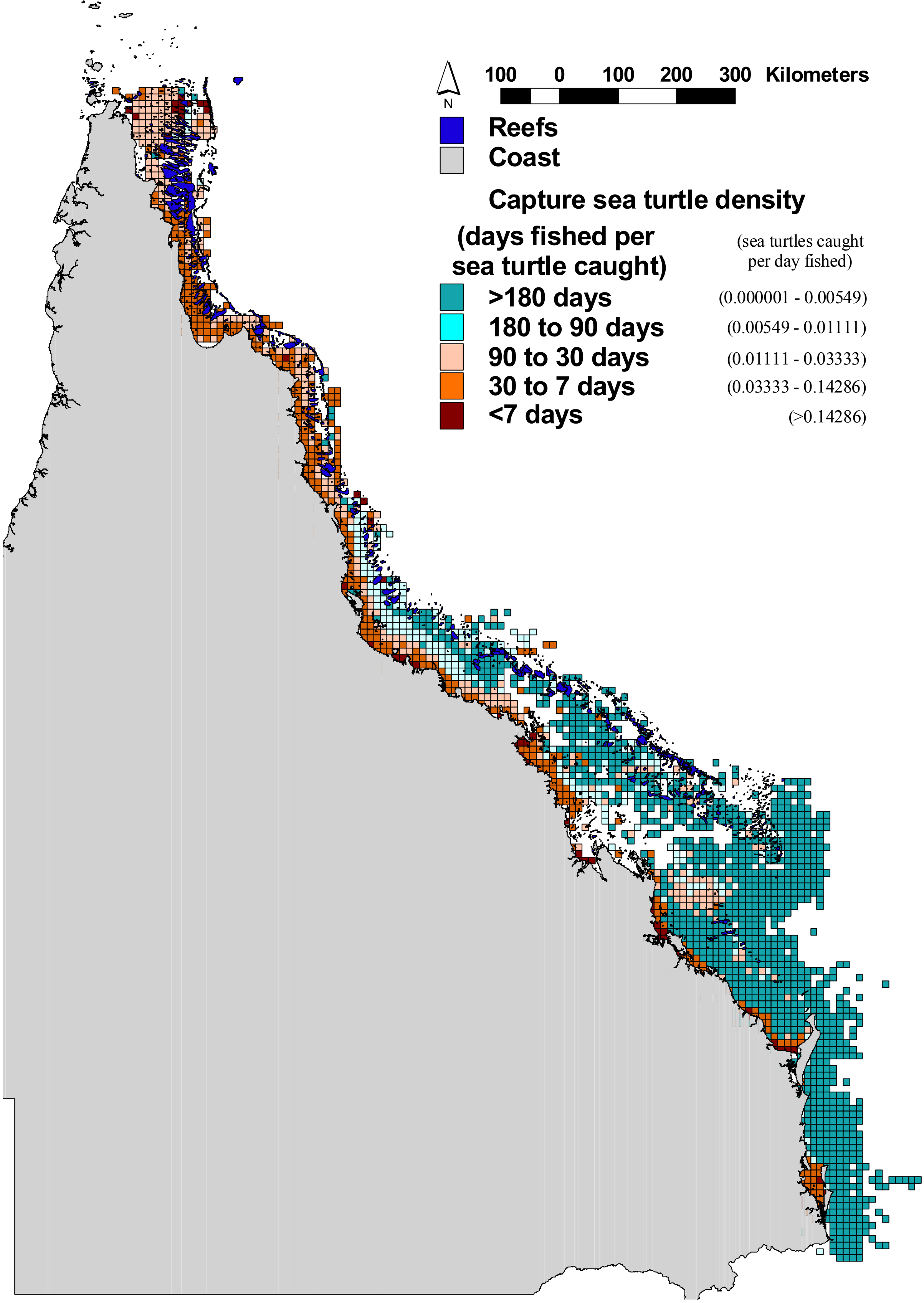


Figure 5.20 Predicted sea turtle CPUE per CFISH site (6^2nm) for *C. caretta*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

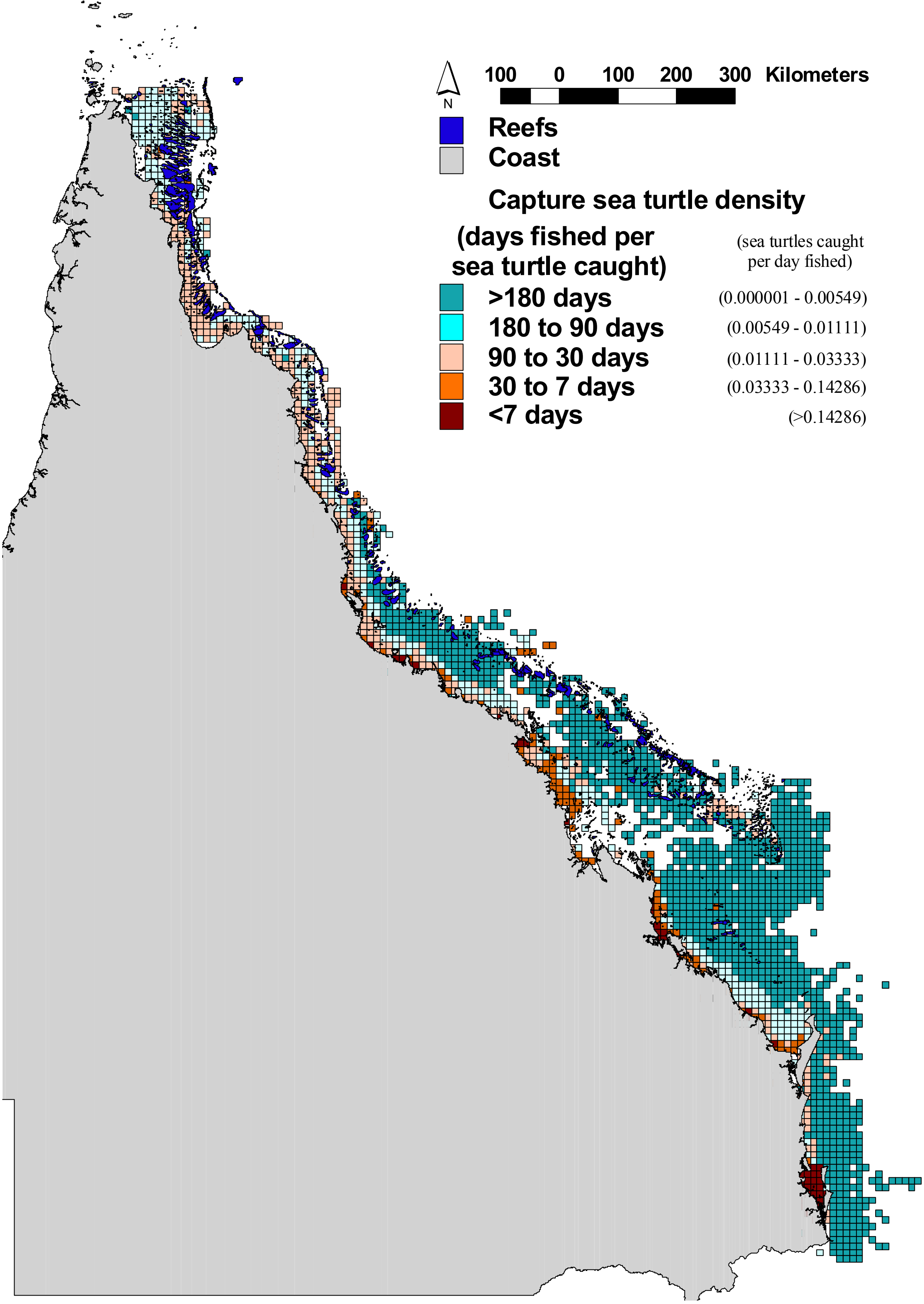


Figure 5.21 Predicted sea turtle CPUE per CFISH site (6^2nm) for *L. olivacea*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).

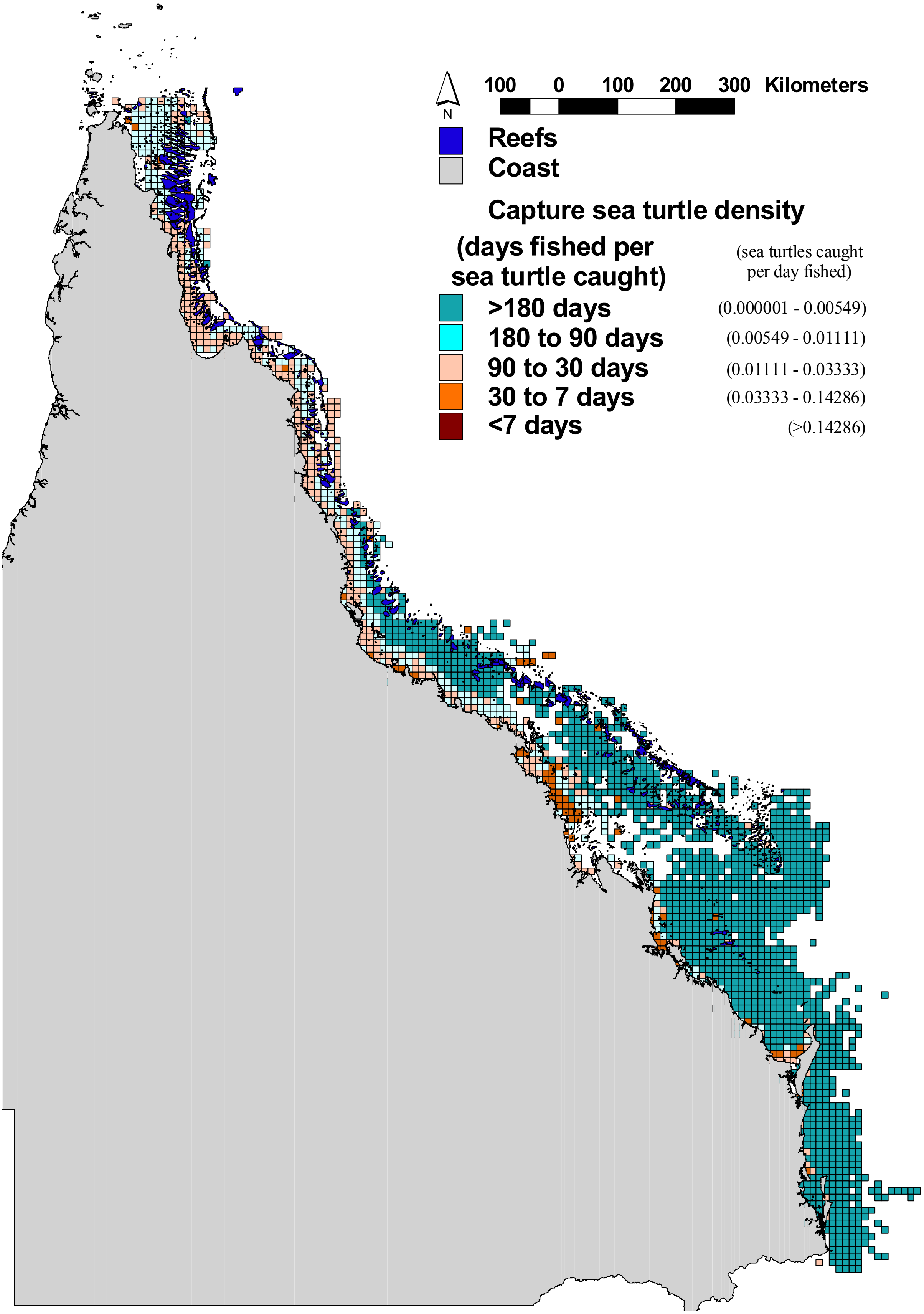
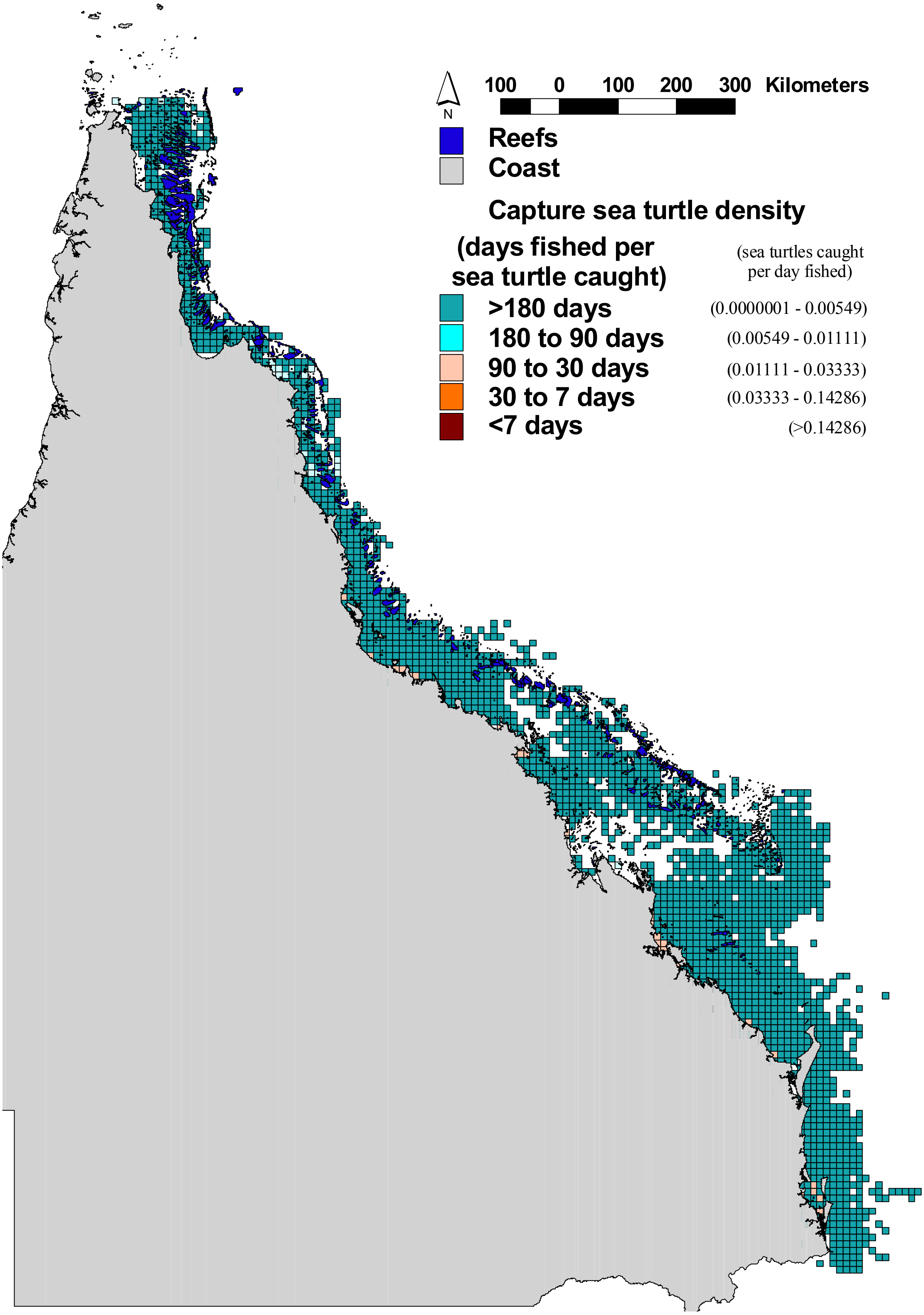


Figure 5.22 Predicted sea turtle CPUE per CFISH site (6^2nm) for *E. imbricata*

Sea turtle CPUE presented as days fished per sea turtle caught (and sea turtles caught per day fished).



5.4.2 In-water sea turtle density estimated aerial survey sightings

A total of 3,209 groups of sea turtles were sighted across all aerial survey blocks. Mean group size was about 1.2 for most survey blocks, but was 2.2 in Moreton Bay (Table 5.11). Group sizes greater than one were assumed to represent individuals seen in quick succession rather than cohesive groups (Marsh and Saalfeld 1990). The higher mean group size in Moreton Bay was attributable to the very high densities of sea turtles on the seagrass beds in eastern Moreton Bay (Limpus *et al.* 1994a). The shallow clear water of this area provided for excellent sighting conditions during the aerial surveys.

Table 5.11 Details of aerial survey sightings of sea turtles for survey blocks

Block (% area sampled)		**No of transects**	**No of transects per site**	**No of $6nm^2$ sites**	**No of groups sighted**	**Group size mean**	**PCF (c.v.*)**	**PCF (c.v.*)**
							Port	**Starboard**
Far northern GBR (8.7%)	Team 1**	82	388	156	939	1.2	1.14 (0.014)	1.14 (0.014)
	Team 2**	114	603	259	929	1.2	1.23 (0.022)	2.61 (0.017)
Central GBR Northern (10.1%)		94	308	108	165	1.2	1.04 (0.017)	1.67 (0.186)
Central GBR Whitsundays (11.7%)		90	281	104	190	1.1	1.24 (0.149)	1.25 (0.094)
Central GBR Shoalwater (10.7%)		61	194	76	358	1.3	1.06 (0.008)	1.19 (0.027)
Southern GBR (11.7%)		46	148	60	70	1.0	1.14 (0.027)	1.21 (0.032)
Hervey Bay (12.1%)		55	201	69	412	1.2	1.10 (0.025)	1.19 (0.030)
Moreton Bay (20.1%)		53	148	33	146	2.2	1.44 (0.161)	1.30 (0.256)

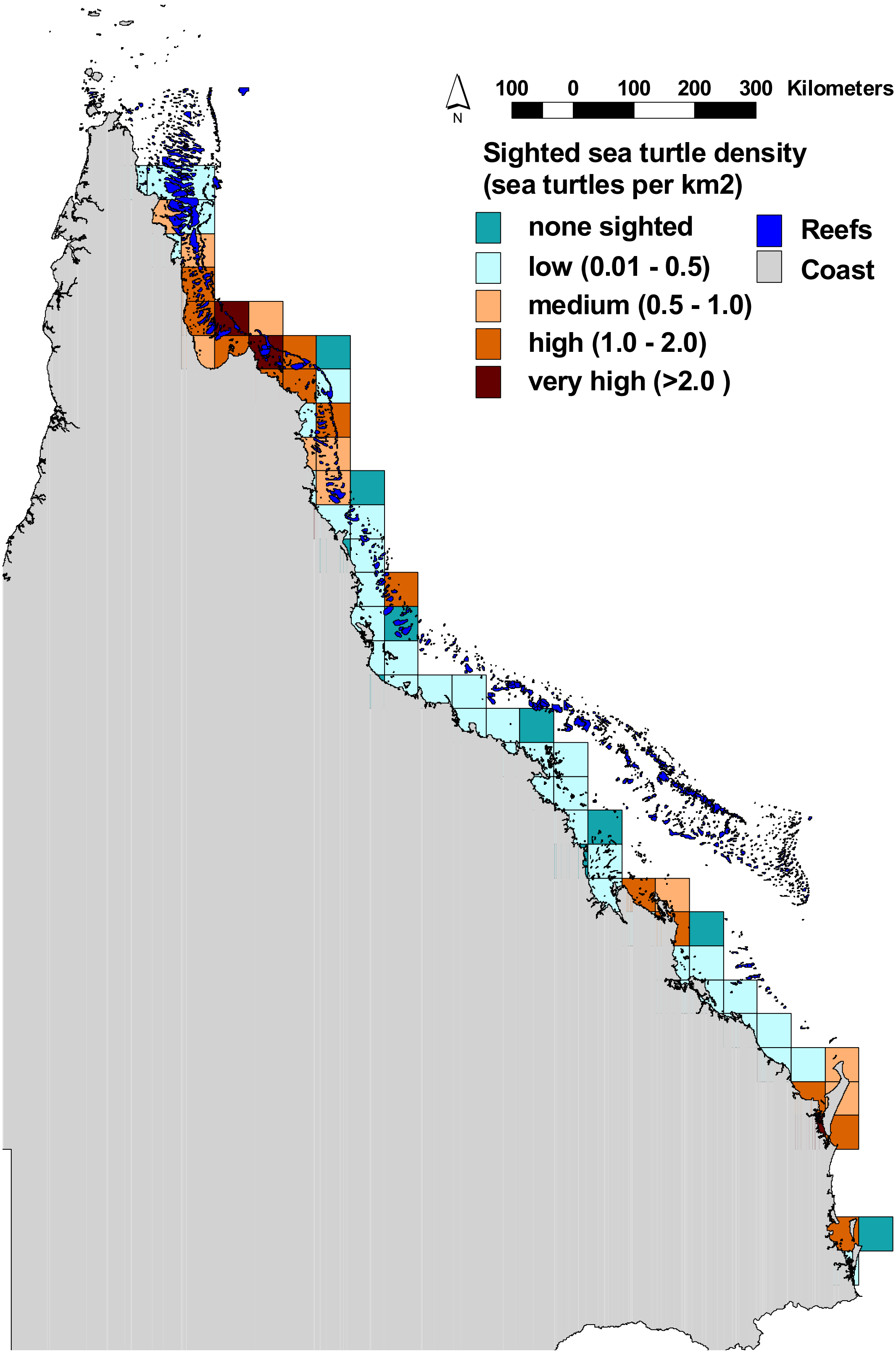
* c.v. = approximate coefficient of variation (Marsh and Sinclair 1989b);

** aerial surveys in the Far northern GBR block were conducted by two teams (in two planes) in order to survey the 39,440 km^2 area of the block in a timely manner, a perception correction factor (PCF) was calculated for each team and applied to the sea turtle sighting reported by that team.

Sighted sea turtle density by CFISH grid (30^2nm)

Sighted sea turtle density (sea turtles per km^2) was calculated for 79 CFISH grids (Figure 5.23). No sea turtles were observed in 12.7% of CFISH grids, 0.01 to 0.5 sea turtles per km^2 were observed in 50.6% of CFISH grids, 0.5 to 2.0 sea turtles per km^2 were observed in 31.6% of CFISH grids and >2 sea turtles per km^2 were observed in 5.1% of CFISH grids. Areas of high sighted sea turtle density were generally associated with large shallow embayments, seagrass areas and reef-shoal complexes in the northern Great Barrier Reef.

Figure 5.23 Sighted sea turtle density (sea turtles per km^2) per CFISH grid (30^{2}nm)

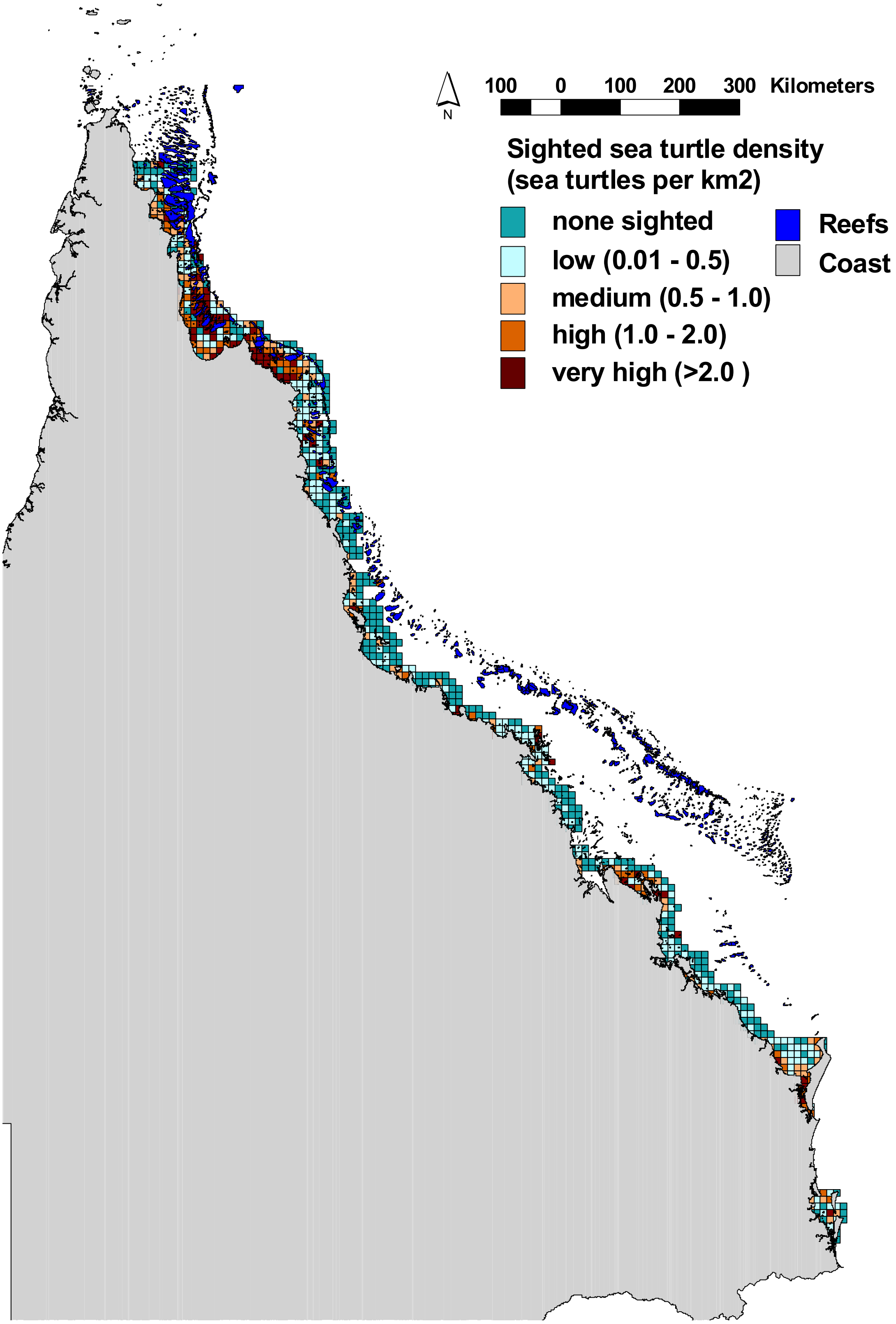


Sighted sea turtle density per CFISH site (6^2nm)

Sighted sea turtle density (sea turtles per km^2) was calculated for 849 CFISH sites (Figure 5.24). No sea turtles were observed in 39.1% of CFISH sites, 0.01 to 0.5 sea turtles per km^2 were observed in 28.8% of CFISH sites, 0.5 to 2.0 sea turtles per km^2 were observed in 21% of CFISH sites and >2 sea turtles per km^2 were observed in 10.7% of CFISH sites.

Areas of high sighted sea turtle density per CFISH site were similar in distribution to the areas of high sighted sea turtle density per CFISH grid and generally included shallow protected waters of the large embayments in southern Queensland (e.g., Moreton Bay, Hervey Bay and Shoalwater Bay), seagrass areas and the reef-shoal complexes of northern Queensland. In addition, waters north-west of Fraser Island had medium to high sighted sea turtle densities (Figure 5.24). The aerial survey in Hervey Bay was conducted in November 1999 and coincided with a known courtship aggregation of *C. caretta* in the waters west of Sandy Cape between September and November (Limpus *et al*. 1984a).

Figure 5.24 Sighted sea turtle density (sea turtles per km^2) per CFISH site (6^{2}nm)



5.5 DISCUSSION

5.5.1 In-water relative sea turtle density as suggested by sea turtle CPUE

GRID versus SITE spatial resolution

Similar trends were apparent in the observed sea turtle CPUE estimated at a spatial scale of 30^2nm (i.e., CFISH grid) as those estimated at a spatial scale of 6^2nm (i.e., CFISH site). Sea turtle CPUE estimated at the spatial resolution of 6^2nm provided greater detail on inshore areas and bays with relatively high sea turtle density. However, the trade-off was a smaller total area where sufficient sampling effort was available. Observed sea turtle CPUE per CFISH site was available for only 820 of the >2,000 CFISH sites over which the Queensland East Coast Trawl Fishery potentially occurs. This discrepancy was overcome by the analysis of trends in sea turtle CPUE with fishing sector, water-depth, season and nesting-ground status and the subsequent prediction of sea turtle CPUE per CFISH site based on fishing sector and water-depth.

The influence of fishing sector of sea turtle CPUE

Results from the present chapter confirmed that sea turtle CPUE was significantly influenced by fishing sector (see Chapter 3). Fishing sector was based on the main target species trawled and reflected factors of aquatic habitats such as water turbidity and bottom substrate in which various prawn and scallop species are found. Sea turtle CPUE was generally higher in the sectors associated with inshore waters. *N. depressus*, *L. olivacea* and *E. imbricata* were caught more commonly in northern Queensland waters while *C. caretta* were caught more commonly in southern Queensland waters, supporting speculation on the latitudinal distribution of these species (Hendrickson 1980; Limpus *et al.* 1983a; Marquez 1990; Musick and Limpus 1996). The tendency for *C. caretta* to have higher relative densities in sub-tropical waters is also supported by trawl-captures of tagged sea turtles; i.e., 63% of *C. caretta* tagged at nesting beaches in central Queensland have been recaptured between Gladstone and the Gold Coast (Limpus and Reimer 1994). These tag returns included 59% from the Moreton Bay area alone (Limpus and Reimer 1994). *C. mydas* were caught in northern and southern waters in approximately equal density, as expected from the hypothetical preferred feeding-grounds (see Chapter 2, section 2.4.1, Table 2.3).

There are no reports in the literature of the influence of habitat type (as indicated by the target species caught by commercial trawlers) on sea turtle CPUE to which the current work can be compared. However, my results suggest that the target species trawled within various fishing sectors can be used as an indicator of preferred sea turtle habitats. Ideally, more specific indicators of sea turtle habitat should be developed (e.g., bottom-type and underwater structure) and measured at broad spatial scales, such as the Queensland east coast.

The influence of water-depth on sea turtle CPUE

Water-depth was also a main factor influencing the sea turtle CPUE in the Queensland East Coast Trawl Fishery, confirming the speculation of Dredge and Trainor (1994). Water-depth influenced sea turtle CPUE for all species combined and each individual species, except *E. imbricata*. Similar trends in the decrease of sea turtle CPUE with increasing water-depth were reported for the Northern Prawn Fishery (Poiner and Harris 1996). Catch rates for all species combined were highest in the 10-to-20 m and 20-to-30 m water-depths in the Northern Prawn Fishery. Similar trends were reported in the USA shrimp trawl fishery of the southern North Atlantic (Henwood and Stuntz 1987), where the highest catch rates of sea turtles occurred in water-depths between 10 and 20 m. However, in the Gulf of Mexico sea turtle CPUE was consistently low (i.e., < 0.01 sea turtles per net hour) for all water-depths, including those <30 m (Henwood and Stuntz 1987).

Predicted sea turtle density distribution

The relative spatial distributions of predicted sea turtle CPUE by all species pooled and for individual species provide quantitative broad scale maps of relative in-water sea turtle density for the majority of the Queensland east coast continental shelf. Previous estimates of relative sea turtle density have been limited to particular habitat types, smaller areas, and by methods that poorly sampled deep or turbid water areas i.e., rodeo-capture and aerial survey (Chaloupka and Limpus 2001; Marsh and Saalfeld 1989; Marsh and Saalfeld 1990). The predicted sea turtle CPUE provided an index of relative sea turtle density at scale of 6^2nm, which is a much finer spatial resolution than the 30^2nm sea turtle CPUE used in a risk assessment by Slater *et al.* (1998).

The relative density distribution of sea turtles presented in this chapter may be erroneous in some locations because the predictive factors (i.e., fishing sector and water-depth) do not explicitly incorporate all facets of sea turtle habitat. Other factors could be included in the predictive model as additional aspects of the critical habitats of sea turtles are quantified i.e., bottom type or underwater structure. Benthic mapping of the Great Barrier Reef is being planned by the CSIRO. This work may shed more light on the aspects of aquatic habitats in the Great Barrier Reef that could be combined with sea turtle CPUE data. Information on bioregion could be included in the predictive model, but any such information would need to improve upon the current spatial stratification (i.e., 6^2nm).

The predicted sea turtle densities may also be erroneous in some locations because of the misrepresentation of the true fishing sector and water-depth e.g., the questionable occurrence of the tiger prawn fishing on the seaward edge of the ribbon reefs in the northern Great Barrier Reef (Figure 5.2). This is an inherent problem associated with the use of non-validated fishery-dependent data. Therefore, the broad scale maps require verification, particularly in areas where the predicted relative density of sea turtles does not concur with reported sea turtle abundance from other sources i.e., rodeo-capture, aerial survey or anecdotal reports.

5.5.2 In-water relative sea turtle density as suggested by sighted sea turtles per km^2

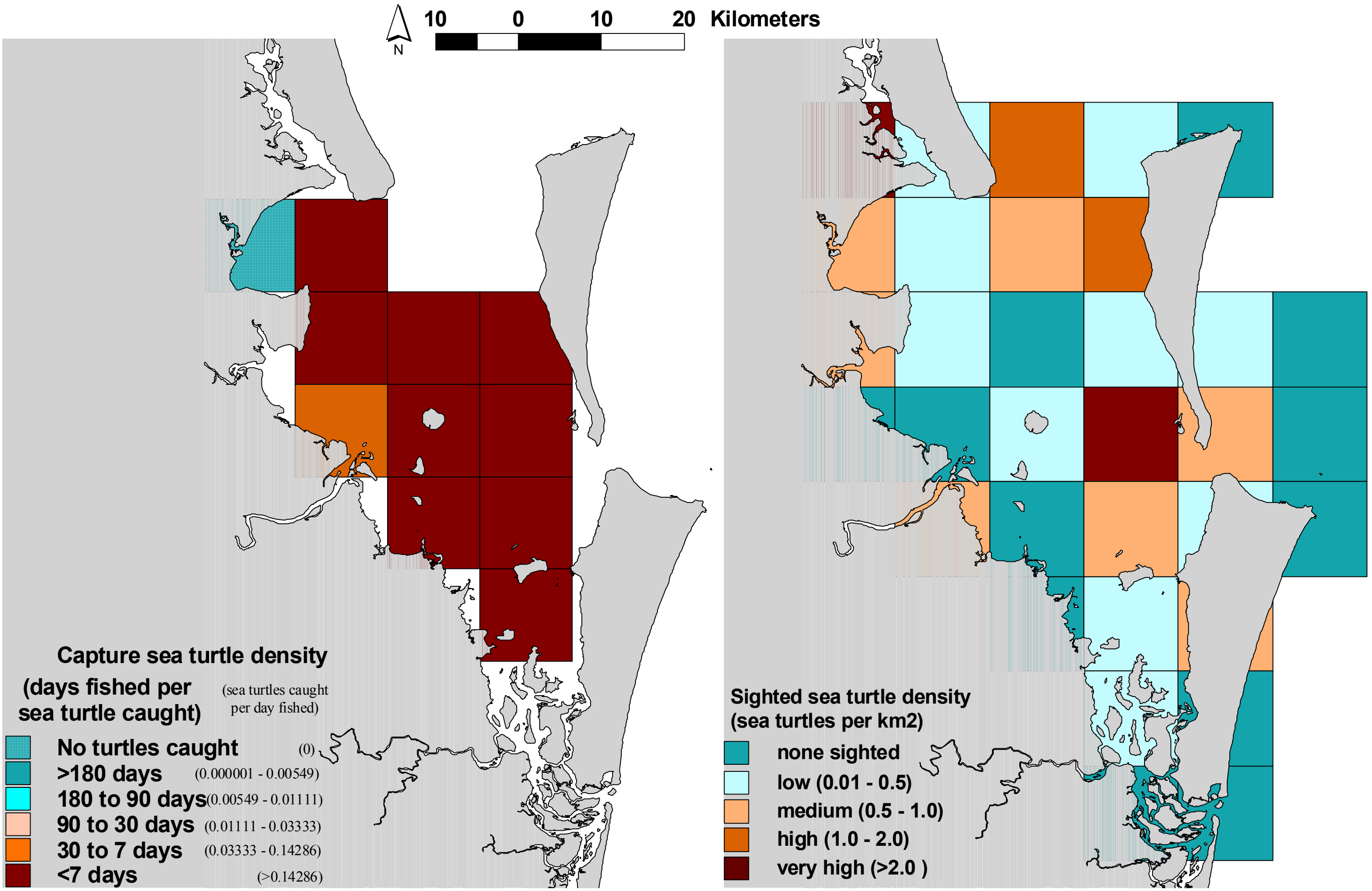
The relative density of sighted sea turtles derived in the current study from aerial surveys was similar to that reported previously for the Far Northern Section of the Great Barrier Reef and southern Queensland (Marsh and Saalfeld 1989; Marsh and Saalfeld 1990). Sighted sea turtle density was high in seagrass areas and on mid-shelf and outer-shelf reef complexes in the Far Northern Section of the Great Barrier Reef. Many of the mid-shelf reefs also support significant seagrass beds of *Thalassia hemprichii* and should be considered as seagrass habitat (e.g., the planar reefs of Princess Charlotte Bay). These habitats would support primarily the herbivorous *C. mydas,* although *C. caretta* are often associated with similar habitats in southern Queensland (Limpus *et al.* 1994b).

The methods of aerial survey used in the current work were the same as that used by Marsh and Saalfeld (1989, 1990) and therefore were directly comparable. The similarity in areas identified with high sighted sea turtle density suggested that the relative spatial distribution of sea turtles has remained stable over the past decade i.e., no major changes in the locations of high sea turtle density. This adds confidence to the use of sighted sea turtle density as a stable measure of relative sea turtle density, albeit within the habitats adequately sampled by aerial survey methods.

Marsh and Saalfeld (1989) noted a lack of sea turtle sightings in soft-bottom habitats with no seagrass, and attributed this to a consequence of water turbidity rather than the true absence of sea turtles. This view was supported by the findings of the current study, where the sighted sea turtle density was low in the central section of Moreton Bay, but the observed sea turtle CPUE for the same area was very high (Figure 5.25). The waters of central and western Moreton Bay are examples of ‘deep’ (i.e., up to 30 m) or turbid waters where submerged sea turtle density was very high but was not reliably detected by aerial survey techniques. Therefore, some caution is required when interpreting sea turtle relative abundance based only on aerial surveys. A lack of sea turtle sightings from turbid waters should not be interpreted as indicating that no sea turtles were present in the area.

Chaloupka and Limpus (2001) estimated the density of *C. mydas* on reefs of the Great Barrier Reef at 45 sea turtles per km^2, which is considerably higher than the highest sighted density of sea turtles per CFISH site recorded in the current study, which was 19.5 sea turtles per km^2. Differences in the estimates of sea turtle density are probably a function of the sensitivity of the ‘capture’ methods used in each study. Aerial surveys cannot ‘capture’ small turtles whereas the results of Chaloupka and Limpus (2001) were based on rodeo-capture, which can capture small turtles. Implications of the sea turtle density estimates of coral reefs by Chaloupka and Limpus (2001) are discussed below.

Figure 5.25 Comparison of observed sea turtle CPUE and sighted sea turtle density for Moreton Bay



5.5.3 Implications of results

Relative spatial distribution of sea turtles

The relative spatial distribution of sea turtles clearly demonstrated that at a broad spatial scale, sea turtles were distributed heterogeneously in aquatic habitats, supporting previous reports that sea turtle densities vary with habitat (Butler *et al.* 1987; Dredge and Trainor 1994; Epperly *et al.* 1995a; Chaloupka and Limpus 2001).

The current study did not include trawl survey captures or aerial survey sightings from the outer-shelf reef habitats from Cairns to the Swains Reef Complex (see section 5.3.4). This is a limitation of the relative spatial distributions presented in this chapter and is a continuing gap in the knowledge of relative sea turtle density in continental shelf waters of the Queensland east coast. However, Chaloupka and Limpus (2001) estimated the mean density of *C. mydas* and *C. caretta* on a sub-tropical reef at 45 and 4.5 sea turtles per km^2, respectively. They suggest that the reported density of *C. mydas* is typical of reef habitats throughout the Great Barrier Reef, and if so, reefs of the Great Barrier Reef should be considered to support extremely high relative densities of *C. mydas*. The density of *C. caretta* throughout the reefs of the Great Barrier Reef is less certain, although the *C. caretta* density reported by Chaloupka and Limpus (2001) is typical of sub-tropical reefs along the Queensland east coast (Dr Colin Limpus, QPWS, personal communication 2002). Therefore, sub-tropical reefs should be considered to support very high densities of *C. caretta*.

Characteristics of very high density areas

Areas of very high relative sea turtle density identified by trawl survey were often associated with embayments and water-depths of <20 m, where tiger, endeavour and banana prawns were the main target species trawled. Areas of very high sea turtle density in southern Queensland were likely to consist of *C. caretta* and *C. mydas*, while areas of very high sea turtle density in northern Queensland were likely to consist of *N. depressus*, *L. olivacea* and *C. mydas*. Areas with very high relative sea turtle density were often associated with seagrass beds, particularly those identified by aerial survey. Some caution needs to be exercised when interpreting the relative density distribution of sea turtles based on aerial survey sightings as not all areas were sampled equally (i.e., in terms of availability bias because of turbid or deep water). Differences between species were not distinguished. Therefore, the relative density distribution based on sea turtle sightings was likely to be biased by the distribution of *C. mydas* because: (i) they are numerically abundant (Chaloupka and Limpus 2001); (ii) they are likely to be the main species sighted by aerial survey in shallow seagrass and reef habitats because of the feeding preferences of this species; and (iii) they are large sea turtles as adults which are not likely to be camouflaged during feeding activities, making this species more likely to be sighted (Dr Colin Limpus, QPWS, personal communication 2002).

Priority area for management – fishing impacts

Fisheries impacts are a concern for all species of sea turtle, but are of particular concern for species listed as endangered or where serious declines in sub-population numbers have occurred. In eastern Australia, significant declines have occurred in the number of nesting *C. caretta* (Limpus and Reimer 1994) and this species is listed under Australian legislation as being endangered (see Chapter 2, section 2.2.1). Therefore, management of anthropogenic impacts on *C. caretta*, particularly incidental fishing mortality, is a priority for management agencies. The options for spatially managing sea turtle by-catch are considered in greater detail in Chapter 6.

The trawl and aerial survey data used in the current analysis have limitations. However, the relative density distributions of sea turtles derived from trawl captures suggested that fishing impacts on *C. caretta* from prawn trawling were probably greatest in waters of southern Queensland, although trawling is excluded from some locations in southern Queensland (e.g., Great Sandy Strait and the ‘Narrows’ between Gladstone and Rockhampton). *C. caretta* also occurs in the lagoons of sub-tropical reefs of the Great Barrier Reef (Limpus *et al.* 1984a; Chaloupka and Limpus 2001). These feeding-grounds provided immature *C. caretta* with a significant refuge from possible trawl capture. However, mature individuals that migrate from refuge feeding-grounds (e.g., coral reefs) would have been exposed to potential trawl capture during courtship and at nesting beaches. Courtship areas and waters adjacent to nesting beaches should be considered as additional areas where *C. caretta* can be protected from ongoing trawl impacts.

Priority areas for management – other anthropogenic impacts

The relative density of sea turtles was generally highest in the shallow inshore waters along the Queensland east coast. These areas are adjacent to cities or regional towns of Queensland, where urban and industrial development pressures are greatest (Zeller 1998). Pollution and alteration of habitats has the potential to impact negatively upon these shallow inshore areas and is likely to be a problem for *C. caretta* in southern Queensland and to a lesser degree for *N. depressus* and *L. olivacea* in northern Queensland. *N. depressus* and possibly *L. olivacea* are of particular concern, because these species do not appear to have a significant proportion of their population amongst the reef or inter-reef habitats of the Great Barrier Reef that have the highest current level of habitat protection. However, these species are present throughout remote northern Australia and therefore may have large proportions of their sub-populations protected from coastal development impacts. Monitoring of sub-populations of *N. depressus* and *L. olivacea* would assist in detecting trends in the sub-population size of these species. Sea turtles of the Queensland east coast are also exposed to indigenous hunting. However, this impact is relatively localised to areas adjacent to indigenous communities and is focused upon *C. mydas*. The relatively high density of *C. mydas* on reefs of the Great Barrier Reef reported by Chaloupka and Limpus (2001) may provide some refuge areas for *C. mydas* from hunting in reefs remote from indigenous communities. However, sub-populations of *C. mydas* should be monitored in order to ensure that major declines in sub-population size are detected before the population of *C. mydas* in Australia is depleted.

Priority areas for management - conservation planning

Shabica (1982) identified two steps when planning for habitat conservation: (i) the identification of the habitat upon which the resource is dependent; and (ii) ensuring that regulations enacted are sufficient to protect the habitat. Along the Queensland east coast, marine habitats are currently protected as Fish Habitat Areas, State Marine Parks via Great Barrier Reef Marine Park zoning or the Commonwealth *EPBC Act* 1999. All four protection mechanisms currently focus on seagrass beds, reefs and estuaries. These protected areas offer a refuge to sea turtles from many anthropogenic impacts, particularly for *C. mydas* and *E. imbricata* on the tropical reefs of the Great Barrier Reef, *C. mydas* and *C. caretta* on the sub-tropical reefs of the Great Barrier Reef, *C.*

mydas in seagrass areas, and to a lesser extent *C. caretta* in protected estuarine areas. From the predicted spatial distributions of relative in-water sea turtle density, it appears that a limited amount of habitat associated with *N. depressus* and *L. olivacea* is currently protected. This is a consequence of the limited documentation of the critical habitats for these species and a general lack of understanding of the role of soft-bottom, turbid-water habitats in the marine ecosystem. The current process of protecting representative areas of biodiversity (i.e., expanding Marine Protected Areas MPAs) within the Great Barrier Reef, which are closed to extractive use, may address this lack of protection of soft-bottom habitats, as the proposed MPA system is based on the protection of representative areas of each type of bio-regions within the GBRWHA.

It appears that *C. mydas*, the most numerically abundant sea turtle species has the greatest protection of critical habitats i.e., coral reefs and seagrass beds, although this species is subject to considerable indigenous harvest, particularly in areas adjacent to indigenous communities (Smith and Marsh 1989; Chaloupka and Limpus 2001) and boat strikes in coastal embayments adjacent to large cities (Haines and Limpus 2000). The challenge for conservation managers is to ensure that critical habitats of all species of sea turtles are identified and afforded the appropriate level of protection. However, habitat protection alone will not ensure the conservation of sea turtles species, but must be considered as part of a number of management interventions to minimise anthropogenic impacts on sea turtles.

The relative density distributions of sea turtles generated in the current study is a starting point to which further information can be added. However, the relative density distribution of sea turtles relies on estimates of habitat type (i.e., main target species trawled) and water-depth. It is essential that the potential errors in the distributions are explored and that predicted sea turtle density is ground-truthed.

Sea turtles are inherently difficult to survey in feeding-ground habitats, particularly deep or turbid waters. Therefore, multiple sampling techniques are required to effectively sample the range of habitats in which sea turtles occur. Dedicated aerial surveys are an accepted technique of surveying the relative abundance of sea turtles (Bulter *et al.* 1987; McDaniel *et al.* 2000). Trawl surveys are more suited for sampling deep or turbid waters and have recently been suggested as the most appropriate technique to in-water survey sea turtles (TEWG 2000). A combination of replicated aerial surveys and stratified trawl surveys designed specifically to sample sea turtle abundance could be used to validate the relative sea turtle densities predicted here. While dedicated trawl surveys are expensive, this type of research would lead to a better understanding of the factors influencing sea turtle densities by providing fine scale spatial information on the substrate type or habitat structures associated with sea turtles in inshore waters particularly for *N. depressus* and *L. olivacea*. In addition, demographic information such as size composition, maturity status and genetic stock structure could be collected from sea turtles sampled by dedicated trawl surveys. The problem of submergence mortality (see Chapter 4) can be overcome by using short tow durations and resuscitation techniques. Indeed, preliminary trawl surveys have been used in the southeastern USA to investigate trends sea turtle abundance[14]. In addition, a systematic program of dedicated sea turtle surveys could allow the calibration of sea turtle density estimates derived from aerial survey and trawl capture surveys.

5.6 CONCLUSIONS

Sea turtles are distributed heterogeneously amongst the diverse habitats that occur along the Queensland east coast. The trawl captures and aerial survey sightings provided observed in-water relative densities of sea turtles. Sea turtle densities were also predicted for most continental shelf waters of the Queensland east coast based on fishing sector and water-depth. The resulting spatial distributions of sea turtle relative density provide the first step towards broad scale maps of the distribution of sea turtles at a scale useful to management.

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[14] Trawl surveys conducted by the Gulf and South Altantic Fisheries Foundation recorded sea turtle abundance although not to investigate population response to TEDs but rather to demonstrate low sea turtle abundances and therefore no need for TED use in those areas (TEWG 2000).