ENVIRONMENT AUSTRALIA

MARINE SPECIES PROTECTION PROGRAM

FUNDING AGREEMENT

WITH

DEPARTMENT OF CONSERVATION & LAND MANAGEMENT, WA

FOR

AERIAL SURVEY OF THE DISTRIBUTION AND ABUNDANCE OF DUGONGS AND ASSOCIATED MACROVERTEBRATE FAUNA - PILBARA COASTAL AND OFFSHORE REGION, WA

COMPLETION REPORT

DR R I T PRINCE

PROJECT MANAGER
CALM

MAY 2001

COMPLETION REPORT

ON

AERIAL SURVEY OF THE DISTRIBUTION AND ABUNDANCE OF DUGONGS AND ASSOCIATED MACROVERTEBRATE FAUNA - PILBARA COASTAL AND OFFSHORE REGION, WA

Progress Against Specific Actions: As per requirements of the contract agreement for Phase 4 of this work -

1. Data analysis to provide population estimates for the dugongs, sea turtles and small cetaceans (dolphins) recorded on survey has been completed.

2. Sightings data have been mapped to show distributions of the dugongs, sea turtles and small cetaceans (dolphins) recorded on survey. Other species sightings were too few to warrant this treatment.

3. These maps products have been produced on Microstation software using the GIS-base data files obtained from the survey. They are included as Figures in the report.

4. The intention was to have the job of data presentation done using Arcview software only. The objectives considered were: to simultaneously convert our raw datasets into the required report Figures; to have our data in a form directly compatible with other similar marine environmental resource database systems, and; to facilitate some further possible spatial analysis that might be desirable prior to producing a manuscript for publication in *Wildlife Research*. Some later misunderstanding of the initial job request intervened.

5. The discrepancy in software use noted above (3. and 4.) was not apparent to me until most of the Figures work had been done, and then only because hard copy drafts were shown to a third party knowledgeable about such matters, as well as being interested in accessing our new data.

6. The need to revert to Arcview presentation of our data for accession to other environmental databases is presently being negotiated with the GIS manager for the North West Shelf Joint Environmental Management Study (NWSJEMS) focus group. NWSJEMS is one of the main Western Australian government client groups external to CALM that will benefit from access to the new data generated from the Pilbara 2000 survey. Proceeding on this course is now the most practicable and cost efficient option available, and will assist in producing summaries for accession to the WA marine resource and environmental management databases, as well as products compatible with the EA Coastal Atlas. Further discussion with the Coastal Atlas managers regarding this matter could be desirable

7. The required final survey report is attached.

As per requirements of the contract agreement for Schedule Item G of this work -

8. Renewed contact with the NWSJEMS being managed from within the Western Australian Department of Environmental Protection in partnership with CSIRO is noted. NWSJEMS is consulting widely with industry, science, and other State government agencies. Availability of our new survey data has already been advised to Chevron Australia Pty Ltd, Woodside Petroleum Ltd, and Apache Energy, major players in the Pilbara region offshore oil and gas industry in Western Australia, plus a number of independent environmental consultants to that industry, and a major fisheries operator.

9. Further communication to industry regarding these new data is planned for the future. Contingency costs for this work, and the further data analysis and manuscript production for formal publication as mentioned under 4. above is part of the project budget.

R I T PRINCE,
PROJECT MANAGER, WADCALM.
30 May, 2001.

Report on the Results of the Survey.

The Distribution and Abundance of Dugongs and Other Megavertebrates in Western Australian Coastal Waters Extending Seaward to the 20 Metre Isobath Between North West Cape and the De Grey River Mouth, Western Australia, April 2000.

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Executive Summary

Dugongs are one of only four living species of the Order Sirenia, and the sole representative of the Family Dugongidae.

The tropical and sub-tropical Australian coastal region is internationally significant for conservation of dugongs.

The relative regional importance of Shark Bay, the Ningaloo Reef tract, and Exmouth Gulf, Western Australia, as dugong habitats has been demonstrated from a range of reconnaissance, research and monitoring studies commenced in the late-1970s.

Early reconnaissance studies of the Western Australian Pilbara coastal and offshore waters also pointed to the significance of this area for dugong, but the regional surveys required to provide information on distribution and abundance of dugongs in that area had not previously been supported.

Funding provided from the Marine Species Protection Program of Environment Australia enabled the first comprehensive aerial strip transect survey focused primarily on the dugong to be undertaken in April 2000.

Results from the Pilbara 2000 survey have revealed a relatively small but widely distributed population of 2 046 (±376 se) predominantly adult dugongs, with the majority of sightings on survey seeming to be distributed in the general pattern first suggested by the late-1970s reconnaissance work. However, practically no dugongs were found within Exmouth Gulf in April 2000. The evidence available suggests that the *c.* 1 000 dugongs formerly found there on mid-year surveys in 1989 and 1994 were not lost, but most probably emigrated elsewhere in response to environmental disruption attributable to severe (Category 5) Tropical Cyclone Vance. TC Vance passed down through Exmouth Gulf in March 1999.

The most likely April 2000 location for most of the former Exmouth Gulf resident dugongs appears to be the Shark Bay World Heritage Area. This matter requires further detailed study.

Findings from our April 2000 survey confirm the regional importance of the Pilbara coastal and offshore waters area as an integral part of the resource areas sustaining dugong presence on the Western Australian coast. The need to consider requirements for dugong conservation at an appropriately wide regional scale is also apparent. Critical connectivity across the Shark Bay to Pilbara coast region at least is indicated. Linkages to areas further north can also be anticipated.

The likely longer term pattern of temporal and spatial variability of capacity of key habitat areas needed to support the Western Australian dugong population provides the reason for the wider focus required. This must be taken into account in review of the current proposals for designation and management of new marine protected areas (MPAs) for the Western Australian Pilbara and other coastal regions extending into the Kimberley.

The international conservation importance of Western Australian tropical and sub-tropical coastal waters and islands for breeding sea turtles independently documented is further supported by our survey. The estimated mixed-species total population of 57 519 (±4 222) predominantly adult Chelonid sea turtles resident within the waters inside the 20m isobath is substantial, but still conservative. Large numbers of turtles were obviously present during our survey in deeper waters beyond the 20m isobath cutoff point for recordings. Small to medium sized juvenile turtles are also less easily detected than adults on survey.

The majority of these resident Chelonid sea turtles are expected to be green turtles. Much smaller populations of flatback, hawksbill and loggerhead turtles generally co-occur. Few, if any, olive ridley turtles are thought likely to be present in Pilbara waters. Leatherback turtles were not sighted on survey, but are known from these coastal waters, and also range much further southward. However, foraging leatherback turtles are now likely to be few in numbers. They might also be found foraging in waters much deeper than any being used by the Chelonid turtles resident in Pilbara waters, and thus occur well outside our survey frame.

Most of the herbivorous green turtles inhabiting the Pilbara region waters are expected to be algal feeders. The dynamics of interaction between environmental disruption likely to follow from tropical cyclones impacting the algal communities and the health of the dependent resident green turtle grazer population is expected to differ from that of the seagrass and dugong system. Better information is required for understanding on both accounts.

The high concentrations of resident Chelonid turtles we have found on survey in some particular circumstances suggest that there is now good reason to review operational environmental management practice where overlap of commercial activity and major resident sea turtle aggregations might occur.

Physiological and other differences become important when seeking comparisons between survey results for the sea turtles, being marine reptiles, and those for dugongs, a marine mammal.

The Pilbara coastal waters support small populations of dolphins, the majority of which appear to be *Tursiops* sp. (bottlenose). Some *Sousa* sp. (humpbacked) dolphins also occur. We have no data relevant to the occurrence or otherwise of the inshore specialist Irrawaddy dolphin, *Orcaella brevirostris*, in these waters.

Other species of dolphins that may occur in waters off the Western Australian Pilbara are more likely to be found in offshore waters deeper than 20m. Thus, absence of records for any of these on our survey is not unexpected.

Large cetaceans frequenting waters off the Western Australian Pilbara are also generally likely to be found in waters deeper than 20m. Further, migratory species such as the humpback whale are expected to be present only in the appropriate season, although some may venture inside the shallower waters of the western half of our survey area, and into Exmouth Gulf in the latter half of the year. The absence of sightings of humpback whales, and the sighting of a solitary minke whale only outside the seaward cutoff boundary of our April 2000 survey area are thus consistent.

No whale sharks, and very few manta rays were sighted on survey. Seasonal and other factors affecting likely patterns of distribution and abundance of these large filter feeding Elasmobranchs, and their food resources, in our survey area are poorly known. We cannot offer further insight into these matters from our observations.

Our data set provides a substantial addition to knowledge of the marine megavertebrate biotic resources of the Pilbara coastal region. These data also highlight deficiencies in our knowledge of the ecosystems and ecosystem processes contributing to support of these animals.

Dissemination of our survey information to appropriate organizations and interested parties should aid in making improvements to environmental resource allocation decisions and environmental management decision making and operational practice, and stimulate further attention to work that might address deficiencies in our understanding of these coastal ecosystems and their dependent megafauna.

Strip transect aerial surveys of the type we have undertaken provide a cost effective method of assessing distribution and abundance of a range of marine megavertebrate fauna. Similarly structured surveys can also be applied profitably to assessment of a range of other visible marine phenomena. This survey technique is nevertheless, only one of a range that might be applied to addressing particular resource assessment problems.

Informed choices of technique(s) available for use must be made when deciding how to proceed with any investigation. Appreciation of the limitations of any methods to be employed is essential. Parameters necessary for correct use must also be complied with. In this context, aerial strip transect surveys are a valuable tool within the armoury available to marine resource managers and biologists.

Full appreciation of the value of sightings data obtainable from such surveys requires further information on behaviours and other factors affecting potential availability to detection on survey of target animals in different settings. Separate studies are required to improve our knowledge of these factors, which are complementary to other data corrections that are routinely derived from the specific survey data being obtained.

'Snapshots' of the distribution and abundance of organisms that may be targeted by these surveys are only part of the data sets needed to understand aspects of population dynamics and ecology. The data produced any single survey should be interpreted in this context.

The Distribution and Abundance of Dugongs and Other Megavertebrates in Western Australian Coastal Waters Extending Seaward to the 20 Metre Isobath Between North West Cape and the De Grey River Mouth, Western Australia, April 2000.

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Summary

Coastal waters of Western Australia from North West Cape to the De Grey River mouth, including Exmouth Gulf and the adjacent offshore islands, and extending seaward to the 20m isobath, were covered by aerial strip transect survey over the period 7 through 15 April 2000. The primary survey target was the dugong. The main secondary survey targets were sea turtles, small and large cetaceans, and the larger filter feeding Elasmobranchs - the whale shark and manta ray. Incidental observations of other probably important marine phenomena also noted on survey will be reported elsewhere.

This first quantitative survey for dugong of the Pilbara coast has confirmed that regionally important focal habitats for dugong are present, and reinforced the view that dugong conservation needs must be considered over a much wider and appropriate temporal and spatial scale. The estimate of 2 046 ($\pm$376 se) dugong present in the Pilbara waters on survey, at an average density of 0.10 dugong km^{-2}, is considered likely to be near the minimum for this area. Extended serial disturbance of feeding habitats resulting from passage of a series of severe Category 5 tropical cyclones in the recent past (1995-2000) is a major factor. The almost complete absence of dugong from within Exmouth Gulf in April 2000 is also considered most likely to reflect major feeding habitat disruption caused by one of these cyclones, TC Vance, passing directly through the gulf in March 1999. Stranded and dead dugong were not being reported from along the Western Australian coast in the months following TC Vance. This, and the relatively small Pilbara dugong population found on our survey, has suggested that the population of *c.* 1 000 dugongs, formerly found in Exmouth Gulf on surveys in 1989 and 1994, could have moved elsewhere. Comparison of our result with the 1989 and 1994 data, together with the unpublished results of Gales and associates from a mid-1999 repeat survey of Exmouth Gulf, Ningaloo Reef and Shark Bay to the south, almost immediately post-TC Vance, support the conclusion that these dugongs may have emigrated into Shark Bay. The mixed-species resident population estimate of 8 481 ($\pm$1 126 se) Chelonid sea turtles for the Exmouth Gulf area at an average density of 2.26 turtles km^{-2}, and of 49 039 ($\pm$4 069 se) at a similar density of 2.46 turtles km^{-2} for the <20m Pilbara coastal waters confirm the global significance of these areas for sea turtle conservation. These estimates are certainly conservative because the sea turtle distributions clearly extend out into deeper waters, the smaller juvenile size turtles are not as readily detected by observers as the mature adults, and necessary corrections for availability on survey are poorly understood. The majority of these turtles are expected to be greens, and these are most likely to be predominantly algal feeders. Algal feeding by the green turtles could help explain part of the difference in apparent response of the sea turtles to the local tropical cyclone impacts regime relative to the seagrass dependent dugongs. Very high density local aggregations of resident sea turtles were found in some circumstances. These concentrations warrant further attention in consideration of environmental management practice. Residual uncertainties raised in interpreting the dugong and sea turtle results point to the need for studies to obtain better knowledge of the soft bottom seagrass resources, and the algal communities on the reef and limestone platform habitats of the Pilbara. The mixed-species small cetacean population estimate of 793 ($\pm$195 se) individuals for the Exmouth Gulf area at an average density of 0.21 dolphins km^{-2} was similar to previous survey results. The Pilbara coastal waters small cetacean population estimate was 1 509 ($\pm$411 se) individuals at an average density of 0.08 dolphins km^{-2}. These dolphins are believed to be predominantly *Tursiops* sp. (bottlenose), with some *Sousa* sp. (humpbacked). We did not find the inshore specialist Irrawaddy dolphin (*Orcaella brevirostris*), the only other species likely to be found in the Exmouth Gulf and Pilbara coastal waters. No large cetaceans were recorded within the survey area, and only one Minke whale was seen in deeper water seaward of the 20m isobath. Seasonal and other behavioural factors are believed to explain this result. No whale sharks were seen, and very few manta rays. Further information is needed to properly interpret these observations. Addition of data derived from this survey to regional marine resource databases will assist in planning of resource allocation for nature conservation and the management of marine activities.

Introduction

The extensive Western Australian coastline borders relatively shallow tropical and sub-tropical marine waters along approximately half its length, from Shark Bay northwards. It has been shown that the waters of the Shark Bay World Heritage Area, the Ningaloo Reef and Marine Park, and Exmouth Gulf include internationally significant populations of dugongs and sea turtles. Populations of some of the other larger marine vertebrates, including small and large cetaceans, and whale sharks and manta rays, are also a feature of the regional megafauna (Preen *et al.* 1997).

Preliminary surveys over the coastal waters northward and eastward from North West Cape previously suggested that this area too included regionally significant dugong and marine turtle habitats with their associated resident populations plus other members of the megafauna (Prince 1986; Prince *et al.* 1981). Considerable progress has since been made in further defining the importance for their dependent sea turtle populations of the regional coastal nesting resource areas, and in linking these with feeding habitats, including those in more remote locations (Prince 1994, 1998).

Similar improvement of knowledge of the regional importance of these north-western Western Australian waters to dugongs and the rest of the megavertebrate fauna is long overdue. Progress on this as an aid to improving marine conservation prospects and providing further focus on the need for developing better environmental understanding and approaches to management practices by industry based in the area has generally been harder to achieve (Preen 1998). Funds provided to the Western Australian Department of Conservation and Land Management from the Marine Species Protection Program administered by Environment Australia have now enabled work on redressing this deficiency. This report presents the results of the first quantitative aerial survey of dugongs and associated marine megafauna completed in April 2000, and discusses the importance of related ecological and environmental management matters arising.

Methods

Study Area

The Western Australian Pilbara offshore waters as mentioned for the purposes of this work extend from North West Cape (*c.* 114°10′E, 21°45′S) northward and eastward up to Poissonnier Point on the east side of Breaker Inlet at the mouth of the De Grey River (*c.* 119°15′E, 20°S; Figure 1). The coastal geomorphology and habitats to the limits of State waters are generally described in Part I, Section 3.6.5, and dealt with in more detail in Part III, Sections 3.4 through 3.11, of the Report of the Western Australian Marine Parks and Reserves Selection Working Group (Marine Parks and Reserves Selection Working Group 1994). Climatically, the coast is arid, with median precipitation in the range 200-300mm per annum, and open pan evaporation potential in excess of 3 000mm per annum. Rainfall is highly variable from year to year, expected over *c.* 20-25 rainy days only. Seasonal incidence grades from uniform around the North West Cape area to summer dominance around the De Grey River. Tropical cyclones crossing the coast over the summer-autumn period usually bring the heaviest rainfalls (Atlas of Australian Resources Vol 4 1986). Some large river systems and numerous smaller watercourses intersect the Pilbara coast. Peak freshwater and sediment discharges into the marine nearshore zone result from extensive run-off from the inland catchments following the heavy rains generated by passage of the tropical cyclones. At most other times, outflow is negligible, with most watercourses drying to chains of pools over the mid-year dry period.

The seaward limit of the coastal waters zone grades into the Rowley Shelf section of the North West Shelf Oceanic Province (Marine Parks and Reserves Selection Working Group 1994; Part I, 3.6.6). Off the western Pilbara coast, this transition occurs along and around the chain of limestone islands generally located within the 20m isobath. These islands extend in an arc from North West Cape out to the Barrow Island - Monte Bello Islands area at 115°30'E, 20°20'S. From the Monte Bellos, the 20m isobath loops back towards the coast. It passes eastward of the Lowendal Islands group, and then reflects to a shore parallel lineament running NE, first passing seaward of the outer Dampier Archipelago islands (Rosemary, Legendre, and Delambre) and thence extending to the eastward end of the study area. Separation from coast to the 20m isobath over this section is generally from 20 to 45 km (Figure 1). In total, the study area described covers approximately 23 700 km^2 (Table 1). The seaward cutoff boundary location for the survey area along the 20m isobath was chosen on several counts: firstly, while dugong feeding trails have been seen elsewhere at depths from 23m (Lee Long *et al.* 1993) to 33m (Lee Long *et al.* 1996), most feeding activity is likely to occur at lesser depths; secondly, the generally subdued inshore bottom slope tends to increase sharply past the 20 m isobath on this coast, suggesting some possible functional ecotone (above, *ibid.*); and, thirdly, the State waters boundary practically coincides with or lies outside this limit for the greater part of the survey target area (Figure 1).

Benthic habitats within this study area include: mudflats, intertidal and subtidal sands, rocky shores and wave-cut platforms, limestone pavements, coral and rocky reef, and soft bottom communities (Bowman, Bishaw and Gorham 1995).

A substantial part of this offshore waters region is the focus of continuing petroleum exploration and production, with associated offshore and onshore installations, including shipping and processing facilities (Figure 2). Exmouth Gulf supports an important long-established prawn trawl fishery, plus further commercial and recreational fisheries. Other prawn trawl, and commercial and recreational fisheries, exploit the waters to the northeast along the main Pilbara coast (Figure 3). There is also an expanding focus on commercial aquaculture within these waters. There are additional very large port developments associated principally with the iron ore and solar salt industries on the mainland coast at Dampier and Port Hedland (Figure 1). Developments to provide a broader industrial base are being planned.

Aerial Surveys

Strip-transect aerial surveys were conducted over the period 7 through 15 April 2000, commencing from Exmouth Gulf, and thence working progressively to termination over the eastern limit of the study area (Figure 1). Timing of the survey attempt was planned to coincide with the expected occurrence of most favourable light winds on this normally windy coast. Water surface condition is critical to efficient observation.

The primary survey plan was structured to optimize day to day logistics for the operation, due to the limitations on access to suitable operating bases and aircraft duration relative to distances required to be covered when on task. The survey time window chosen also allowed for the best chance of minimizing differences in tidal water movements affecting the particular areas being surveyed while doing the work - the Pilbara coast is subject to semi-diurnal tides, with an April spring tide range of *c.* 2m at Exmouth Gulf increasing to *c.* 6m at Port Hedland, but which latter has a neap tide range of *c.* 2.5m only (National Tidal Facility 2000).

Survey methods followed Marsh and Sinclair (1989a, 1989b), with survey protocols as detailed in Marsh *et al.* (1994) for the first survey of Shark Bay, WA. All transect lines were spaced at 2.5' latitude (4.65km or 2.5nm), and transect lines within survey blocks were generally aligned perpendicular to the ecological axis of the particular area as this results in greater precision of the population estimates. Thus, survey lines within the Exmouth Gulf sector were aligned East-West, as before, and for the other previous Western Australian work where the major coastline trend was predominantly North-South (Preen *et al.* 1997). The trend of the coast for the remainder of this Pilbara offshore study area required transect alignments approximately NW - SE to intersect the ecological axes. In contrast with E - W transects, where the sun will generally be over the wing and to the north side of the aircraft on survey, NW - SE transect alignments change the sun angles relative to flight paths. Observers on the sun side may have to cope with more direct light on their window, and reflected glare will differently affect their viewing fields. The relative angle of below surface light penetration striking submerged animals that might be visible also changes. These consequences could not be avoided in this case, but observers could partially compensate for some of these difficulties by concentrating their attention on that part of the viewing field least affected by glare. Routine use of neutral tinted Polaroid sunglasses on survey also helps to reduce the effect of glare from the water surface.

Survey tasks were planned to avoid flying early morning and late afternoon, and during the middle of the day, when glare and below surface light penetration factors would be least favourable for observations, and attempted when expected sea surface conditions would be ≤ Beaufort state 3, and cloud cover <4 oktas. Observations were made at the survey standard operating combination of: altitude 137m, ground speed of 185km h^{-1}, and by pairs of observers independently scanning 200m wide survey strips on each side of the aircraft.

Using a mark-recapture analysis of the survey sightings data for the two members of each observer team, perception-bias correction factors were calculated to compensate for the animals otherwise visible, but not recorded as being seen by the observers (Marsh and Saalfeld 1989). Separate perception-bias correction factors were calculated as necessary for both the port and starboard observer pairs for each of the primary survey target fauna groups, *viz.*, dugongs, marine turtles (turtles), and small cetaceans (dolphins).

Some of the survey target animals present will also be invisible to observers, due to their being too far below the water surface to be seen. Adjustment to compensate for this is made when deriving abundance estimates from records of sightings by the use of 'availability correction factors' (ACFs). ACFs standardise the proportion of the animals noted as being at the water surface when sighted against the proportion found at the surface in previous experimental surveys over clear shallow water where all animals could be seen (Marsh and Sinclair 1989). Appropriate data for the dugongs and turtles only are available. We have no data to allow an ACF adjustment to be made for the dolphins. It should be noted that these ACFs are conservative, as the reference value for the proportion of animals at the surface when sighted is higher than estimates derived by other means (Marsh and Sinclair 1989).

Results

Survey Programme

Aerial marine fauna surveys of this type can be completed successfully only where the field programme attempt coincides with timely persistence of the necessarily restrictive required operating conditions. Fortuitously, the Pilbara 2000 survey attempt was completed between the dates 6 and 16 April 2000 - the minimum time practicable for the work using one aircraft, including pilot and survey crew.

Planned timing of the field work fitted our survey within the window found between the diminishing regional flooding after effects attributable to the early March 2000 passage of Tropical Cyclone (TC) Steve along the Western Australian coast (Figure 19), and the subsequent closing out of opportunity mid-April 2000, due to the approach of TC Rosita from the north. Premature termination of the survey was narrowly averted when TC Paul, building in the Timor Sea area from 11 April 2000, tracked westward, moving far out into the Indian Ocean (Bureau of Meteorology data).

Exmouth Gulf and Offshore Islands Area

Dugongs

Two dugongs only were sighted on transects for this survey, comprising two separate sightings of single adult size dugong (Figure 4). These data are too few to allow independent calculation of a reliable population estimate for this area. The estimate of 95 (±62 se) dugong calculated using correction factors derived for the Pilbara (Table 1) suggests there were less than 100 dugongs present.

Turtles

Four hundred and fifty-four (454) turtles were sighted on the Exmouth block transects for this survey. The majority of turtles sighted were dispersed sufficiently to be recorded as single individuals, or in small groups of generally less than five individuals, but where turtles were particularly abundant, observers also often aggregated sequential sightings data before reporting to expedite efficient recording. Thus, the numbers of turtles per group as recorded on task do not necessarily imply any functional behavioural relationship integrating the activities of the turtles being counted. Some further aggregation of recorded sightings has also occasionally been required to facilitate display of these data (Figure 5). Only Chelonid turtles were seen on survey, but observers were not equally proficient at in-flight species identifications. Nevertheless, most of the turtles sighted can confidently be assumed to have been green turtles. Some loggerhead, hawksbill and flatback turtles, much fewer in numbers than the green turtles, would also have been present. Noting this, the estimated mixed Chelonid sea turtle population for the Exmouth block on this survey was 8 481 (±1 126 se) individuals, at an average density of 2.26 turtles km^{-2}.

Small Cetaceans - Dolphins

Fifty (50) dolphins in 18 groups of 1 to 8 animals were sighted on transects within the Exmouth block for this survey. The sightings data (Figure 6) do generally indicate the numbers of animals estimated to form functional groups. The majority of the dolphins sighted, and those positively identified by the experienced observers participating on survey, were believed to be *Tursiops* sp. *Sousa* sp. are also known from the Exmouth Gulf area (Preen *et al.* 1997). The estimated population of dolphins for the Exmouth block on this survey was 793 (±195 se) individuals (Table 1), at an average density of 0.21 dolphins km^{-2}.

Other Taxa

Five manta rays only were sighted in Exmouth Gulf. We sighted no whales or whale sharks within the Exmouth block on this survey.

Pilbara Coast and Offshore

Dugongs

Fifty-four (54) dugongs were sighted on the Pilbara block transects for this survey, comprising 43 separate sightings of single adult size dugong, 4 groups of 2 dugong, and 1 group of 3 dugong (Figures 7 - 9). Mean group size was 1.12 (± 0.34 se). The estimated population was 2 046 (±376 se) dugong, at an average density of 0.10 dugong km^{-2} (Table 1).

Turtles

Two thousand, six hundred and thirty-one (2 631) turtles were sighted on the Pilbara block transects for this survey. The majority of turtles sighted were dispersed sufficiently to be recorded as single individuals, or in small groups of generally less than five individuals, but where turtles were particularly abundant, sequential sightings data were frequently aggregated by observers before reporting to expedite efficient recording. Thus, the numbers of turtles per group as recorded on task do not necessarily imply any functional behavioural relationship integrating the activities of the turtles being counted. Some further aggregation of recorded sightings has also occasionally been required to facilitate display of these data (Figures 10 - 12). Only Chelonid turtles were sighted on survey, but observers were not equally proficient at in-flight species identifications. Nevertheless, most of the turtles sighted can confidently be assumed to have been green turtles, but some much fewer loggerhead, hawksbill and flatback turtles would also have been present. Noting this, the estimated mixed Chelonid sea turtle population for the Pilbara block on this survey was 49 039 (±4 069 se) individuals, at an average density of 2.46 turtles km^{-2}.

Small Cetaceans - Dolphins

Two hundred and twenty-seven (227) dolphins in 18 groups of 1 to 15 animals were sighted on transects within the Pilbara block for this survey. The sightings data (Figures 13 - 15) do generally indicate the numbers of animals estimated to form functional groups. The majority of the dolphins sighted, and those positively identified by the experienced observers participating on survey, were believed to be *Tursiops* sp. *Sousa* sp. are known from the Exmouth Gulf area (Preen *et al.* 1997). The estimated population of dolphins for the Pilbara block on this survey was 1 509 (±411 se) individuals (Table 1), at an average density of 0.08 dolphins km^{-2}.

Other Taxa

Large filter feeding vertebrates were scarce within the Pilbara block for this survey. We sighted no whales on transects. A solitary minke whale was sighted *c.* 15km to the west of Thevenard Island outside our survey block in waters deeper than 20m. Five manta rays were sighted, comprising one group of three, and two solitary individuals. No whale sharks were sighted.

Combined Sightings Data

Survey sightings data for the Exmouth block and the consolidated Pilbara offshore sectors are combined in Figures 16 -18, for dugongs, turtles, and small cetaceans respectively.

Discussion

Blocks on Survey

There is no obvious biologically significant boundary separating the coastal waters within Exmouth Gulf, and out to the offshore islands, from those of the remainder of the Pilbara coast, although the general orientation of the ecological axes does differ. Division of the survey cover and resultant data into two main blocks in analysis is thus largely a matter of convenience. Prior data from similar quantitative aerial surveys covering Exmouth Gulf only (Preen *et al.* 1997; area equivalent to transects 1 through 18 of the current survey) are also available for comparison. The offshore and islands transects (19 - 22) within the Exmouth block were being covered for the first time only in our April 2000 survey.

Dugong and Dugong Habitats

It is clear from the sightings data that dugongs were scarce within Exmouth Gulf mid-April 2000, and much fewer in comparison with the 1989 and 1994 survey results. Dugong population estimates derived from these latter surveys suggested *c.* 1 000 dugongs might be found within Exmouth Gulf, whereas the mid-April 2000 survey estimate suggests a population of <100. Two questions are thus raised: What is the possible reason for this change? - and; Where might these nearly 1 000 dugong have gone?

The substantial answer to the first question above is believed to be change in the availability of seagrass forage within Exmouth Gulf as a consequence of habitat damage wrought by severe TC Vance, which passed southward through the middle of Exmouth Gulf on 22 March 1999 (Figure 19). The main answer to the second question seems likely to be a consequent mass movement of dugongs elsewhere. We have no data suggesting any increase in the numbers of dugong carcases being discovered on the Western Australian coast in the 12 months between our survey and the prior passage of TC

Vance (Prince, unpubl. data). Losses of some dugongs by stranding on the *c.* 5m storm surge created as TC Vance approached and then entered Exmouth Gulf (Bureau of Meteorology: Perth Tropical Cyclone Warning Centre 2000) may have occurred (*cf* Marsh 1989), but there are no cases documented. Formal investigation for this purpose could not be financed. Even so, losses of as few as *c.* 5 - 10% of the population are most unlikely to have gone unnoticed.

The total of 54 dugong sighted, and the population estimate of 2 046 ($\pm$ 376 se) at an average density of 0.10 dugong km^{-2} for the Pilbara waters also suggest that dugong were not particularly abundant in that area mid-April 2000. However, the dugong sighted on this latest survey within the Pilbara waters were found in locations where previous observations from longshore surveys (Prince 1986; Prince, Anderson and Blackman 1981, Figure 1), incidental reports (*eg*, Prince *et al.* 1995; various environmental impact assessment reports, and other unpubl. data), and strandings records (Prince, unpubl. data) suggested they generally ought to have been present.

Noting the difference between the longshore and reconnaissance survey approach previously used (*ibid.*), and the aerial strip transect method employed for the April 2000 survey, the actual sightings data across all recorded surveys span the period from February 1977 through April 2000. The general consistency of these sightings locations data supports the view that the Pilbara coastal and offshore waters area does include some very important focal dugong habitats. These waters are thus an integral part of the resource areas sustaining dugong presence on the Western Australian coast.

The relatively low April 2000 abundance of dugongs in this Pilbara area (*cf* Marsh *et al.* 1994, Table 4 data, and discussion; and Table 3 in Preen *et al.* 1997), and the apparent emigration of dugongs from within Exmouth Gulf post-TC Vance (Gales *et al.* 1999 survey - report, *in prep*; and current data), requires some further consideration.

Tropical cyclones are the most obvious major regional temporal and spatial disturbance factor affecting the quality of key dugong habitats along the Pilbara coast, and at a wider regional scale. The likely extent and severity of soft-bottom seagrass habitat disruption being caused by passage of particular cyclones will certainly depend on the characteristics of the cyclone, including intensity and duration of the event, and the track followed. The Exmouth Gulf and Pilbara coastal habitats had been impacted by a number of severe (Category 5) tropical cyclones, including TC John, TC Vance, TC Olivia, and TC Bobby (Figure 19), in the *c.* 5 years immediately preceding our survey. Some other less intense systems which might still have wrought more widespread ecologically important but qualitatively different changes in the nearshore waters have also passed through the region, *eg*, the longshore passage of TC Steve (Figure 19) immediately prior to our survey job, and the resultant regional flooding event.

There is little doubt that the intense wave action and water movements generated by the Category 5 tropical cyclones mentioned above can disrupt soft-bottom habitats across the entire coastal waters within the 20m isobath area targeted for our survey (Scott Condie, *pers. comm.*). Substantial coastal erosion may also occur. TC Vance had attained severe intensity and developed a wide 'footprint' by March 20, 1999, while moving south-westerly offshore from the west Kimberley coast. Vance sustained this intensity and size for the duration of its further passage coast parallel and thence down into Exmouth Gulf on March 22, 1999. Dunefields backing the Eighty Mile Beach were severely eroded by high water levels and wave action early on (C. & J. Lewis, *pers. comm.*, including photographs). Similar coastal erosion from the *c.* 5m storm surge as Vance approached Exmouth Gulf was evident around the Onslow - Tubridgi Point area, and at Exmouth itself (Bureau of Meteorology: Perth Tropical Cyclone Warning Centre 2000). It seems most probable that Vance could have had the greatest single impact on the coastal waters and coastline habitats of significance to Western Australian dugong populations in the recent past.

The three other most recent severe tropical cyclones of interest here (Figure 19) generally approached the Pilbara coast on steady courses from seaward to the north or north-westward, so tending to confine their major disturbance impacts to a lesser, but still substantial part of the coast and coastal waters area. However, local event and cumulative impact histories are also relevant to consideration of likely habitat quality status across the area being surveyed.

The early-mid March 2000 passage of TC Steve and resultant flooding and sustained freshwater and silt discharges into the whole of the nearshore waters zone within our survey area following heavy rainfalls of *c.* 100 - 300 mm over catchments of all the regional drainage systems has been mentioned above. Substantial drainage was still occurring as we conducted our survey, with generally extensive turbid outflow plumes extending seaward from each drainage system. Apart from the evident turbidity within those outflow plumes affecting water mass characteristics, and the potential sightability of survey target fauna therein, we have not yet been able to access tools to further examine the siltation events associated with those plumes. Other possible short-term effects on animal behaviour and distribution, and the benthic habitats, are presently unknown.

Severe TC John crossed the Pilbara coast over the eastern half of our survey area near Depuch Island mid-December 1999 (Figure 19). John did cause some considerable redistribution of bottom sediments in that area (N. Miller, *pers. comm.*), and other damage to coastal property extending *c.* 30km eastwards toward Port Hedland. The relatively recent disturbance of the benthos due to TC John could still have been exerting direct pressure on dugong distribution within the area affected at the time of our survey. Interaction with the previous coastal disturbance in this same area due to TC Vance in March 1999 (above) could also be expected.

Likewise, before turning to move down into Exmouth Gulf, TC Vance also impacted the waters of the western part of our survey area between the Dampier Archipelago to offshore islands (Monte Bellos, Barrow, Lowendals). A major part of this same area was previously affected by the passage of TC Olivia mid-April 1996, and TC Bobby late-February 1995. Unfortunately, we lack any particular detailed knowledge of the extent and condition of the soft-bottom seagrass communities expected to be utilized by the resident dugong in this region. However, there is no doubt that the serial substantial disturbance of such benthic communities will adversely impact and influence the availability of sea grass forage for dugongs.

The best documented example of this effect is the Hervey Bay, Queensland event, triggered by cyclone associated disturbance and flooding in February 1992, which led to the loss of *c.* 1 000 km^{-2} of seagrass which was supporting a considerable local dugong population (Preen *et al.* 1995), the consequent loss of most dugong from that area (Preen and Marsh 1995), and the subsequent slow recovery of the seagrass community and dependent dugong population (*eg*, Lawler and Marsh, *in prep*). Heinsohn and Spain (1974) had previously reported the disruptive impact of a Queensland tropical cyclone on dugongs and the nearshore biota. Tropical Cyclone Sandy, which tracked coast-parallel in the SW Gulf of Carpentaria for some distance in March 1985, was also found to have caused substantial lasting damage to seagrass beds in the region (CSIRO 1990).

The paucity of specific knowledge of the Pilbara seagrass communities and their particular status re dugong forage resource availability certainly needs to be rectified if we are to better address dugong conservation needs in this area, and to better appreciate the current population status. By inference, this may well now be at the bottom end of the possible range of abundance for the Pilbara coastal and offshore region. Certainly, the Exmouth Gulf residual population now includes very few dugongs.

Following from the above, the previous dugong occupants of the Exmouth Gulf area seem unlikely to have been drawn to move further up the Pilbara coast, and the sightings and population data noted suggest that they did not move there. The body of evidence available, including data from Gales *et al.* (1999 survey - report, *in prep.*) does suggest that most of these dugong, and their confreres from the Ningaloo Reef tract, probably have emigrated into the Shark Bay World Heritage Area post-TC Vance. This matter requires further detailed study.

Turtles

Substantial marine turtle populations were documented by our survey. Within Exmouth Gulf, the 454 turtles sighted included 386 (85% of total) on transects 1 - 18 (Exmouth Gulf frame; Area = 3 180 km^{-2}), and another 68 (15%) on the new transects 19 - 22 (Area = 575 km^{-2}) extending out around the Muiron Islands. Proportionally, these turtle sightings are distributed similarly to the area of waters covered within the two transect groups. By comparison, our sighting of 386 turtles within Exmouth Gulf on this occasion is well above any previous records: 262 in 1989; and 115 in 1994 (Preen *et al.* 1997). The proportional population estimate of *c.* 7 200 within Exmouth Gulf from the total of 8 481 ($\pm$ 1 126) turtles exceeds either of the previous survey estimates of 4 512 ($\pm$ 877) for 1989, and 3 252 ($\pm$ 684) for 1994 (*ibid.*). There is, however, a seasonal environmental difference to be accounted for among possible reasons in seeking an explanation for this finding.

Previous Exmouth Gulf surveys were conducted mid-year (June - 1994, or July - 1989), while our survey was conducted through April 2000. Sea surface temperatures across the whole of our survey area for this latter period were *c.* 30-31°C, with a day-night cooling differential of *c.* 1°C only (Remote Sensing Services, DOLA, Leeuwin Centre). Mid-year temperatures within Exmouth Gulf are generally about 7-10°C lower. Core body temperatures for Chelonid sea turtles, even at mature adult size, generally reflect seawater temperatures, with only a usually small or negligible positive differential (Sato *et al.* 1994; Read *et al.* 1996). Metabolic consequences for these ectotherms of a possible 6-8 °C difference in core temperatures of the turtles resident within Exmouth Gulf across these survey times, and likely linked behavioural differences, could be extremely important. The same turtles in the warmer waters situation could well be more active, and, thus, potentially more available for detection on survey than when found in the same area within much cooler waters at a different time. Further research information is needed to define what these consequences might be in particular circumstances.

The average sea turtle population densities within the range of 2.2 to 2.5 turtles km^{-2} derived from our population estimates for the Exmouth and Pilbara waters lie in the mid-range of densities found elsewhere in Australian tropical waters on similar aerial surveys. These April 2000 survey average densities for the more tropical waters area of Western Australia are consistent with the idea that sea turtle populations might be expected to be more abundant in the warmer waters part of their distribution. However, we can also see that average turtle population density for mid-year along the Ningaloo Reef tract is still much higher than this (Preen *et al.* 1997). Apart from the possible clearer waters effect on survey efficiency over the Ningaloo Reef, a survey in this region does cover a much greater proportion of reef edge/ 'drop off' zone extending into deeper waters where the turtles may be further aggregating. Further information clearly is required to put such comparisons in context.

Our April 2000 survey frame was terminated offshore at the 20m isobath in deference to the expected distribution of the primary survey target, the dugong. Numerous casual observations were made during the aircraft turns seaward of the 20m isobath while repositioning between the ends of alternate transects. These observations suggested that sea turtles were generally as common through the deeper waters areas being traversed on these turns as they were being sighted inside the seaward ends of the adjacent transects when data were being recorded. Thus, our cumulative observations suggest that 'clipping' of the survey area boundary at the 20m isobath is reasonably done for the dugong population resident in this area, but this is certainly not valid for the Chelonid sea turtles. These can forage at depths much greater than 20m. Fortunately, some other contemporary aerial survey transect data including sea turtle observations overlapping/adjoining seaward of our offshore boundary zone for a substantial part of the survey area are available to assist our interpretation.

Woodside Petroleum Ltd. is supporting a current marine aerial surveys programme (Francis Baronie, *pers. comm.*) that includes waters of the northern part of the Ningaloo Reef and the Muiron Islands area. This overlaps part of our April 2000 survey area. Transects extend out beyond the continental shelf break, and cover waters ranging from *c.* 10 to 20m at the landward end of transects to *c.* 1 000m at the seaward end. Chelonid sea turtles are being sighted frequently in waters >50m depth, or greater (S.G. Wilson, *pers. comm.* 2001).

Further to the above, there were some very high density aggregations of resident Chelonid sea turtles seen in particular circumstances across the waters being over-flown during our survey, but with data by numbers only formally recorded when turtles were found on transects. This observation deserves further consideration in the context of sea turtle ecology and marine environmental management practice. Generally, and extending on both sides of the assumed location of the 20m isobath around offshore islands and reefs, Chelonid sea turtles appeared to be quite abundant and well distributed throughout the entire visible depth of the water column. Chelonid sea turtles also appeared to be particularly abundant over other reef and shallower waters areas; *viz*, Barrow/Monte Bello/Lowendal islands area, and in similar circumstances extending from the Muiron Islands at the SW end of our survey area up to North Turtle Island on the NE. High numbers of turtles in shallower waters were also detected in other places; *eg*, the east side of Giralia Bay in Exmouth Gulf, and some Pilbara coastal areas.

The fact that resident sea turtles might be particularly abundant in certain places is not surprising, although we don't yet necessarily know the exact reason(s) for the observed patterns of concentration of these resident turtles. Feeding and resting behaviours might well be implicated. Resolution of these matters requires further study. Our current work, and the previous surveys mentioned have not covered breeding aggregations. These latter present a special case currently recognized in Western Australian environmental management practice for activities of the offshore petroleum industry (Pendoley 1997). Further study is also in progress (Pendoley, *pers. comm.*).

Finally, the resident sea turtle population detected by our survey was widely distributed and relatively abundant across the whole of the Exmouth Gulf, Exmouth offshore, and Pilbara coastal waters. In this respect, the mixed-species sea turtle population present seemingly does not reflect any particular response to the environmental disruption of soft-bottom communities expected to have resulted from the impact of recent severe tropical cyclones in Exmouth Gulf in particular. In contrast, dugongs seem to have vacated these same waters, presumably through consequent lack of available seagrass forage. The substantive reasons for this apparent difference may have both physiological and ecological bases, although the difference in detectability of the smaller (*c.* 35-50cm carapace length) juvenile sea turtles among the sea turtles present on survey might also be of further relevance to our interpretation.

The major contrast likely to be involved in our finding of this apparent difference is between the mammalian, seagrass dependent herbivore, the dugong, and the predominant marine reptilian herbivore, the green turtle, as the main component of the regionally resident mixed-species Chelonid sea turtle population.

The green turtle does overlap the dugong as a seagrass grazer in some circumstances, but is also physically better able to feed on the hard-reef tropical species of seagrass such as *Thalassia hemprichii*. Unlike the dugong, which appears to turn to algae as a food source only when seagrass is likely to be unavailable (Spain and Heinsohn 1973), green turtles can quite happily get by on an algal diet (Brand-Gardner, Lanyon and Limpus 1999; Forbes 1996; Garnett, Price and Scott 1985), although they also may feed on plant material other than seagrasses or marine algae where this is available (*eg*, Pendoley and Fitzpatrick 1999; Limpus and Limpus 2000). The nature of the benthos for much of our survey area is offshore reef and limestone habitats more conducive to support of the algal communities likely to be utilized by green turtles. It is thus reasonable to assume that the major part of the resident green turtle population could be algal feeders.

Clearly, some more extensive future investigation of this matter of regional green turtle diet composition is desirable. For now, we can consider the possibility that the macro-algal and algal turf communities expected to provide green turtle forage are less affected by the passage of tropical cyclones than are the soft bottom communities where the dugong usually feed. Alternatively, drifting macroalgae dislodged by cyclone induced wave action may continue providing a green turtle forage resource long after they first become detached.

No long-term studies of algal communities on the Western Australian reef and limestone platform habitats of the Pilbara are available, so we cannot be certain how these might be damaged by cyclones. Studies of this nature are required. The observation on survey of widely distributed and generally extensive rafts of detached floating macroalgae with associated sea turtles, some at least of which appeared to be feeding on the algae, suggests that the second possibility has validity. However, we cannot be sure these algal rafts are comprised of the most nutritious species ordinarily favoured by green turtles. Further investigation of this matter is also warranted.

The inherent physiological metabolic difference between the ectothermic green turtle, and the endothermic dugong, will also allow the turtles to better adjust to potential nutritional stress over a longer period than is tolerable for the dugong. Further consequences will nevertheless accrue for the turtles with prolonged shortage of abundant and nutritious food. The fact that regional green turtle breeding effort has been minimal for two of the last three seasons (1998/99 and 2000/01; Prince, WAMTP unpubl data) is indicative. However, linkage of these events with any possible cyclone effects on algal forage resources of the Pilbara coastal waters is likely to require much more complex explanation.

Dolphins

The distribution of April 2000 sightings of dolphins within the Exmouth block is slightly biased towards the new offshore islands group of transects relative to the areas included (total sightings: 50; 36 = transects 1-18, Area = 3 180 km^{-2}; 14 = transects 19-22, Area = 575 km^{-2}). Assuming that this indication of actual distribution is correct, then the mixed-species dolphin population estimate of 793 (± 195 se) in total comprised *c.* 570 individuals within Exmouth Gulf, plus 223 within the new offshore islands transect area. The 570 dolphins estimated for Exmouth Gulf is only slightly greater than the 1989 estimate of 496 (± 123 se), which was not significantly different from the 1994 estimate of 283 (± 93 se: Preen *et al.* 1997). As previously (*ibid.*), the dolphins seen are believed to be predominantly *Tursiops* sp., with some *Sousa* sp., but species identifications could not be confidently determined for most of these. Apart from *Tursiops* (bottlenose) and *Sousa* (humpbacked) dolphins, the only other small cetacean most likely to be found in the Exmouth Gulf and Pilbara coastal waters, is the inshore specialist Irrawaddy dolphin (*Orcaella brevirostris;* Bannister, Kemper and Warneke 1996, Table 2, *et seq.*) We have insufficient information presently to further discuss these particular data. However, the Exmouth Gulf dolphin population also appears to have responded differently to the more recent tropical cyclones mediated environmental disturbance than the dugong. This apparent difference between the two marine mammal groupings may simply reflect the dolphin carnivore/dugong herbivore dichotomy relative to the anticipated habitat changes. Further information is needed for better understanding of this matter.

The average density of 0.08 km^{-2} for the Pilbara waters mixed-species dolphin population was similar to the average of 0.09 (± 0.03) km^{-2} calculated for Exmouth Gulf from the 1994 survey (Preen *et al.* 1997), but less than half the April 2000 estimate of 0.21 km^{-2} for the entire Exmouth block. Nevertheless, these dolphin density estimates all lie within the range of values obtained similarly for a wide range of other Australian localities (Preen *et al.* 1997, Table 5).

Other Taxa

No whales or whale sharks were sighted within the Exmouth or Pilbara waters survey blocks. Whale sharks also were not sighted in the deeper waters adjacent to our survey blocks, but a solitary minke whale was sighted in the deeper waters area *c.* 15km westward of Thevenard Island. Manta rays were relatively few too, with only 10 being sighted on survey.

The scarcity of any large filter feeding vertebrates from the <20m coastal waters we surveyed in April 2000 could simply suggest that these waters generally do not provide suitable feeding or other habitat for these animals. The majority of whale, whale shark, and manta ray sightings reported by Preen *et al.* (1997) for Shark Bay (Figure 6, *ibid.*), and Ningaloo Reef and Exmouth Gulf (Figure 10, *ibid.*) were obtained from waters $\geq$ 20m depth. Other factors affecting seasonal distributions could also be important. Certainly, migratory humpback whales are not expected to be present in the region we covered outside of the period *c.* mid-year to October, and most of the other larger cetaceans possibly frequenting this region are more likely to be found in deeper water (Bannister, Kemper and Warneke 1996, Table 2, *et seq.*; Jenner, Jenner and McCabe 2001). Whale shark presence along the Ningaloo Reef also appears to be seasonally determined, with a peak usually in the period March through May (Colman 1997; Taylor 1994), but large numbers may sometimes be seen outside that period (*eg*, mid-July 1989, Preen *et al.* 1997). It is also clear that whale sharks are generally present around the northern end of Dirk Hartog Island off Cape Inscription in January (Prince, unpubl. obs. 1994 through 2000; C. & J. Shankland, *pers. comm.*). However, other features of the biology of these whale sharks and the factors generally affecting their distribution off the Western Australian coast are still poorly known. Likewise, focussed local studies of manta ray distribution and biology have not yet been undertaken.

Apart from the absence of the filter-feeding whale sharks and general scarcity of manta rays mentioned above, very few medium to larger-sized sharks and rays of other species were recorded on survey. Further comment on this finding here is not warranted by available data.

Concluding Remarks

The 20 year plus insight into dugong populations of the Pilbara region together with our current survey data support the view that the Pilbara coastal and offshore waters area does include some very important focal dugong habitats. These waters are thus an integral part of the resource areas sustaining dugong presence on the Western Australian coast. Further, the April 2000 population of dugongs in this Pilbara area is relatively small. The apparent southward emigration post-TC Vance of most previously resident dugongs from within Exmouth Gulf (and most likely from part of the Ningaloo Reef tract too) to augment the resident large Shark Bay population, reemphasizes the need to consider requirements for dugong conservation at an appropriately wide regional scale. The indicated likely pattern of longer term temporal and spatial variability of capacity of key habitat areas needed to support the Western Australian dugong population points to critical connectivity across the Shark Bay to Pilbara coast at least.

Linkages to areas further north can also be anticipated. These matters must be taken into account in review of the current proposals for designation and management of new marine protected areas (MPAs) for the Pilbara coastal region, as previously suggested by Preen (1998). The paucity of knowledge of Pilbara seagrass communities and their particular importance as key dugong forage resources must also be addressed. Substantial progress in this regard has now been made in considering dugong management needs for the Great Barrier Reef province on the Queensland coast (Great Barrier Reef Ministerial Council 1996; Preen and Morissette 1997).

Our new data on sea turtle populations shows that the Pilbara coastal waters include some areas apparently supporting very high concentrations of resident turtles, and confirms that this mixed species population does comprise an extremely important regional conservation resource of global significance. Feeding and resting Chelonid turtles are also found aggregated in deeper waters seaward of the 20m isobath.

Accepted environmental management practice for the offshore oil and gas industry presently recognizes the importance of planning marine work programmes around seasonal aggregations of breeding turtles, as well as accommodating the migratory paths of large cetaceans such as the humpback whale. Attention to areas of high concentration of resident turtles now appears warranted. Documentation of developmental habitat areas with high concentration of juvenile turtles and special attention to management of these is also needed. Further study and monitoring of the status and health of the macroalgal and algal turf primary producer communities likely to be supporting the majority of green turtles in this region is also desirable. Better information on the distribution and abundance of, and habitat usage by the other species of sea turtles in this region is required.

It is noted that there is an appreciable Commonwealth waters zone overlapping the area we surveyed off the eastern half of the Pilbara coast (Figure 1).

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Table 1. Pilbara 2000 Aerial Survey: Summary of Results for Dugongs, Sea Turtles, and Small Cetaceans (Dolphins).

Block	Area (km^2)	Survey intensity	Dugongs		Turtles		Small Cetaceans - Dolphins	
			Correction factors (cv)	Population estimate (± s.e.)	Correction factors	Population estimate (± s.e.)	Correction factors	Population estimate (± s.e.)
Exmouth	3755 km^2	8.64%	Mean group size 1.12 (0.344) Port perception correction factor 1.364 (0.060) Starboard Perception correction factor 1.875 (0.1224) Availability correction factor 2.679 (0.180)	95 (±62)	Mean group size 1.302 (1.17) Port perception correction factor 1.261 (0.007) Starboard Perception correction factor 1.31 (0.007) Availability correction factor 1.441 (0.069)	8481 (±1126)	Mean group size 2.368 (0.945) Port perception correction factor 1.042 (0.013) Starboard Perception correction factor 1.893 (0.060) Availability correction factor	793 (±195)
Pilbara	19949 km^2	8.81%	Mean group size 1.12 (0.344) Port perception correction factor 1.145 (0.060) Starboard Perception correction factor 1.35 (0.1224) Availability correction factor 2.679 (0.180)	2046 (±376)	Mean group size 1.302 (1.17) Port perception correction factor 1.115 (0.007) Starboard Perception correction factor 1.123 (0.007) Availability correction factor 1.441 (0.069)	49039 (±4069)	Mean group size 2.368 (0.945) Port perception correction factor 1.019 (0.013) Starboard Perception correction factor 1.309 (0.060) Availability correction factor	1509 (±411)
Total	23704 km^2			2141 (±381)		57519 (±4222)		2302 (±455)

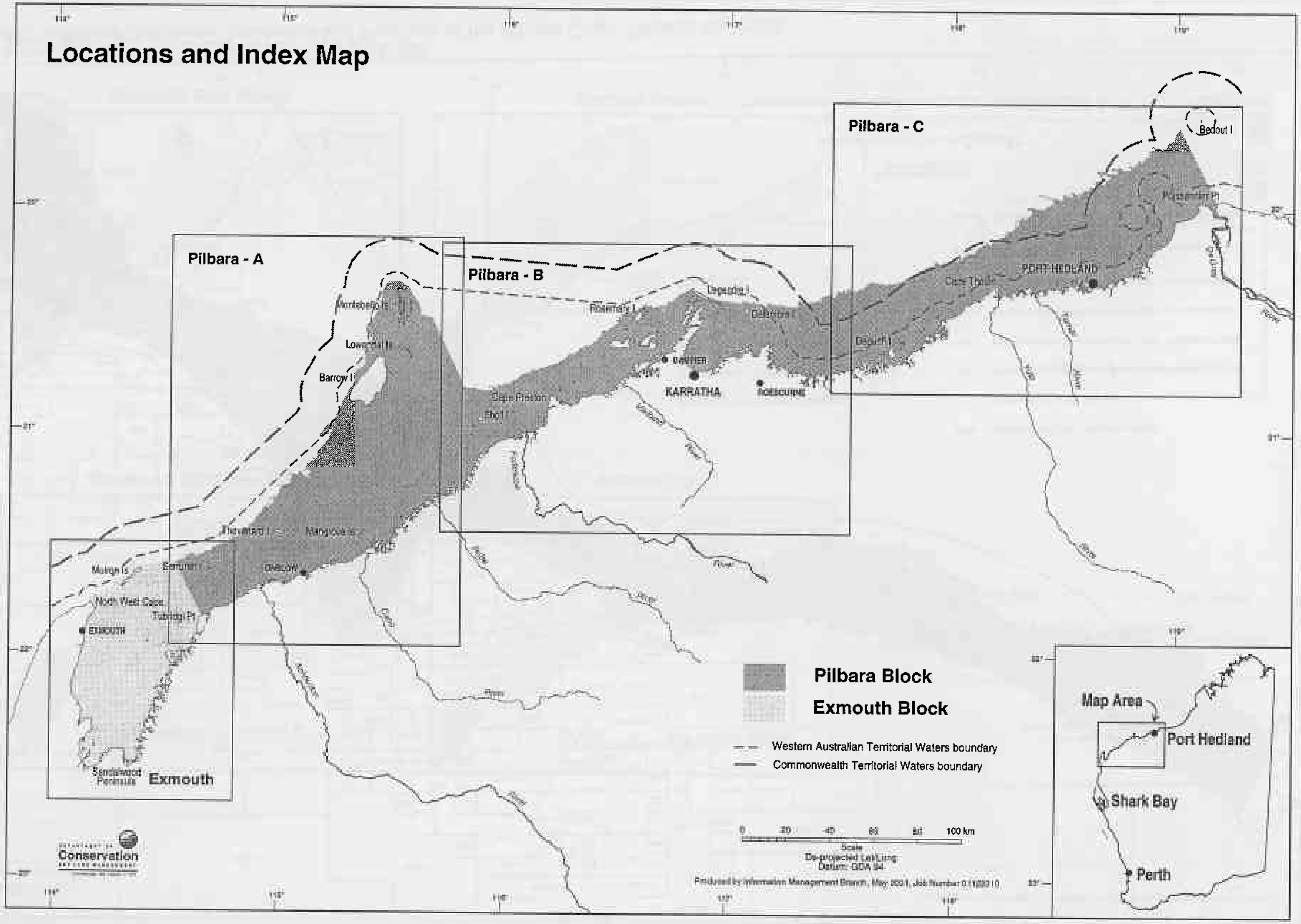

Figure 1. Pilbara 2000 Survey: Area Locations and Index Map

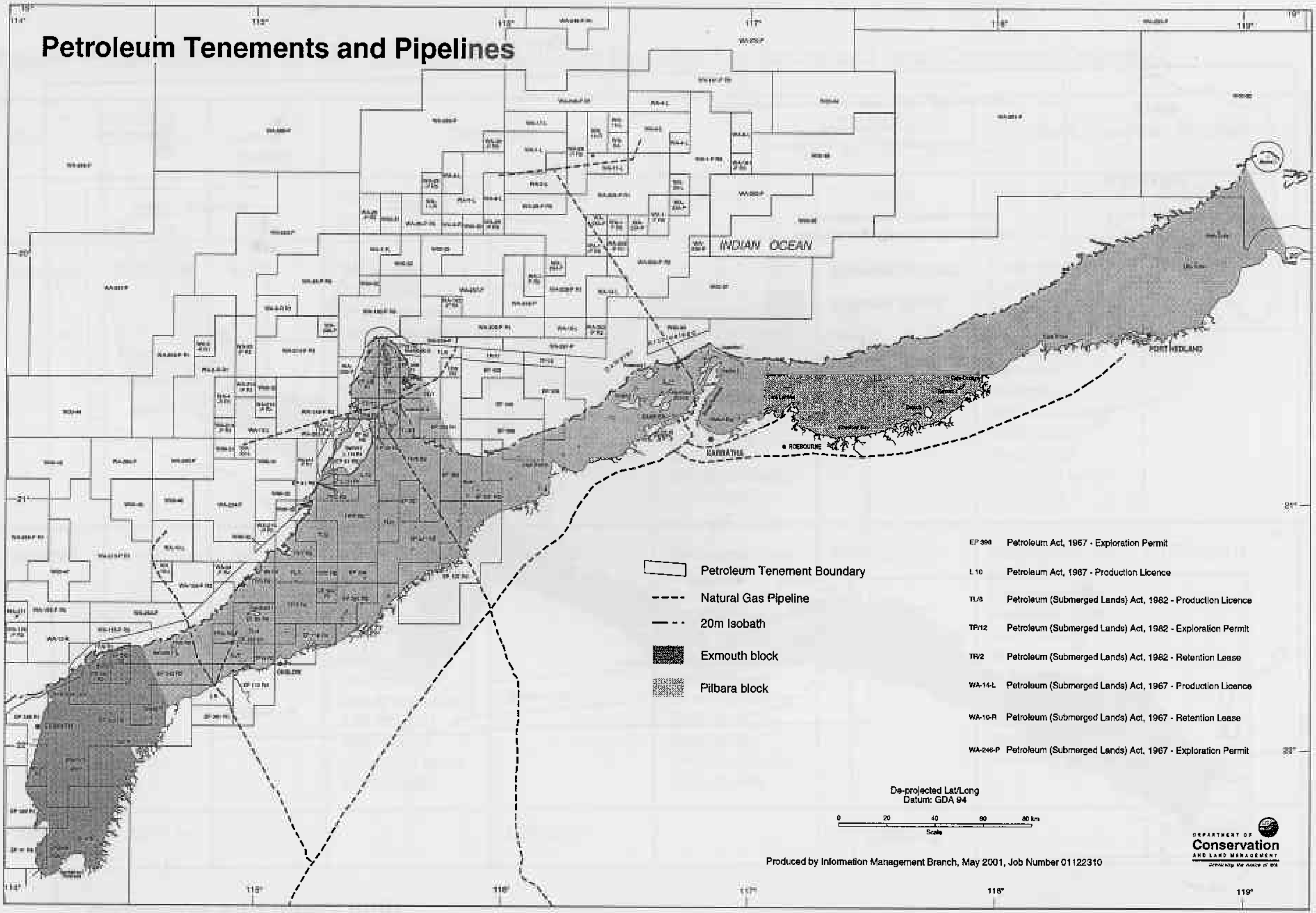

Figure 2. Offshore Petroleum Tenements and Pipelines of the Pilbara Coast, Western Australia.

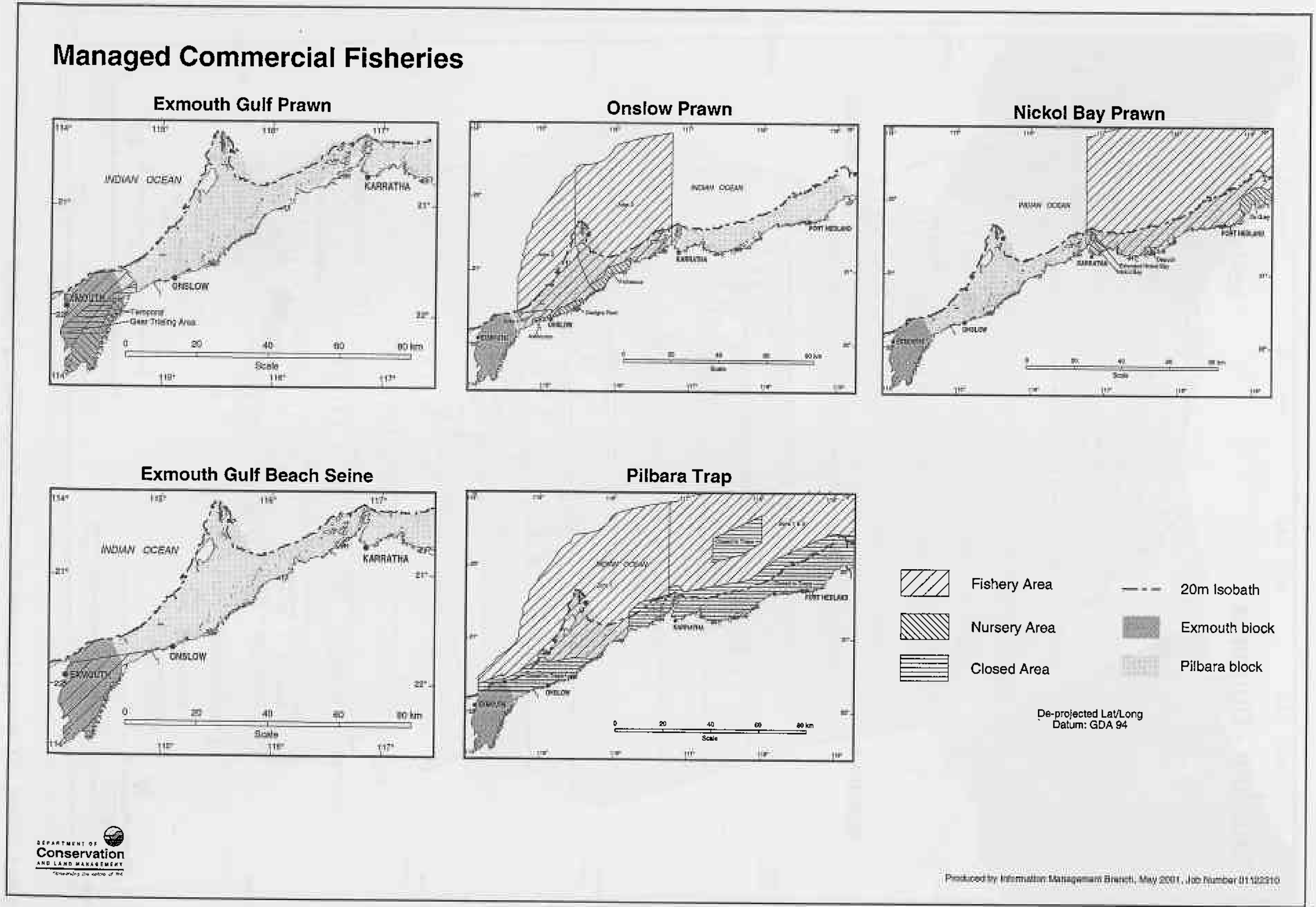

Figure 3. Managed Commercial Fisheries of the Pilbara Coast, Western Australia.

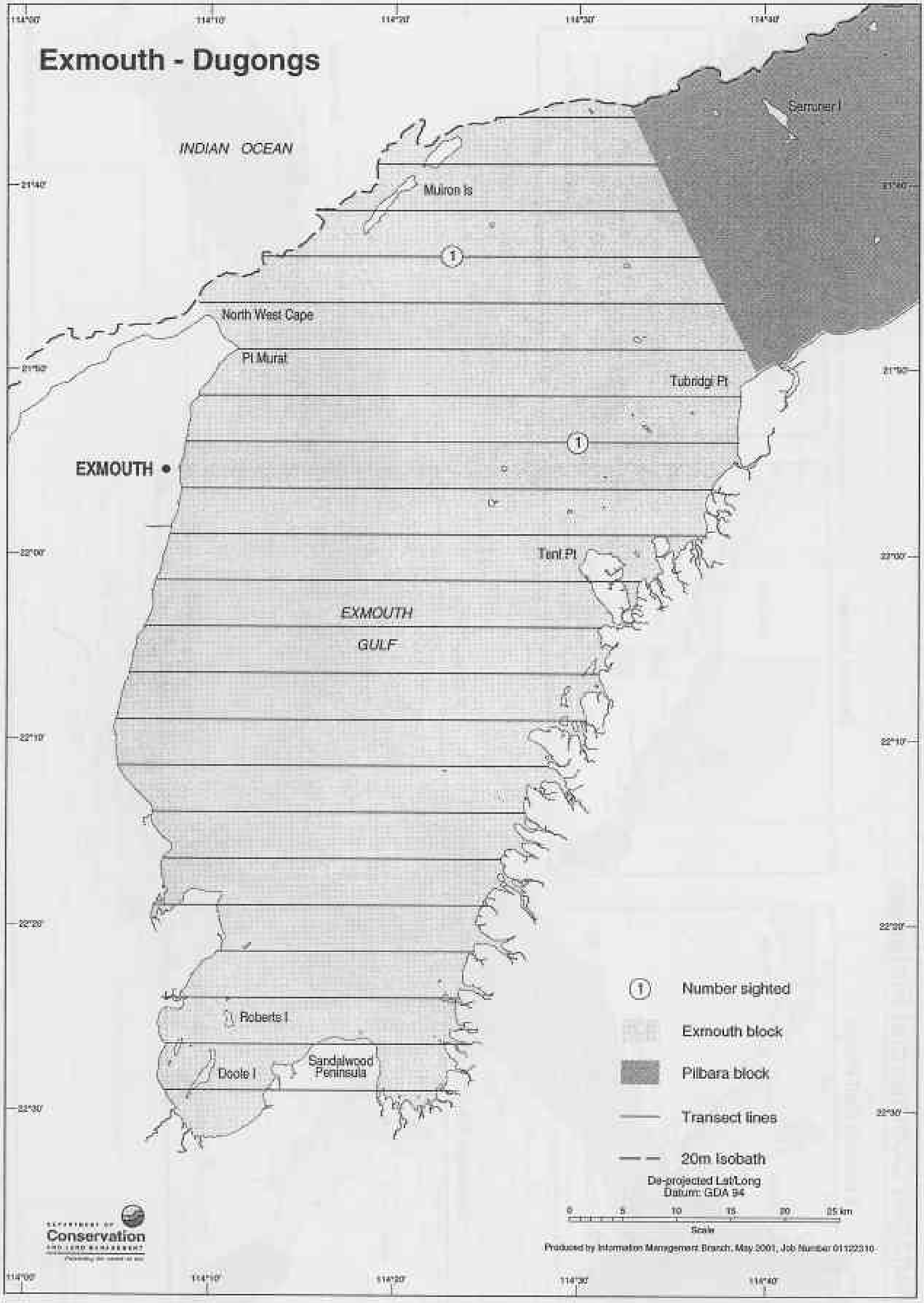

Figure 4. Pilbara 2000 Survey: Exmouth Block Transects and Dugong Sightings.

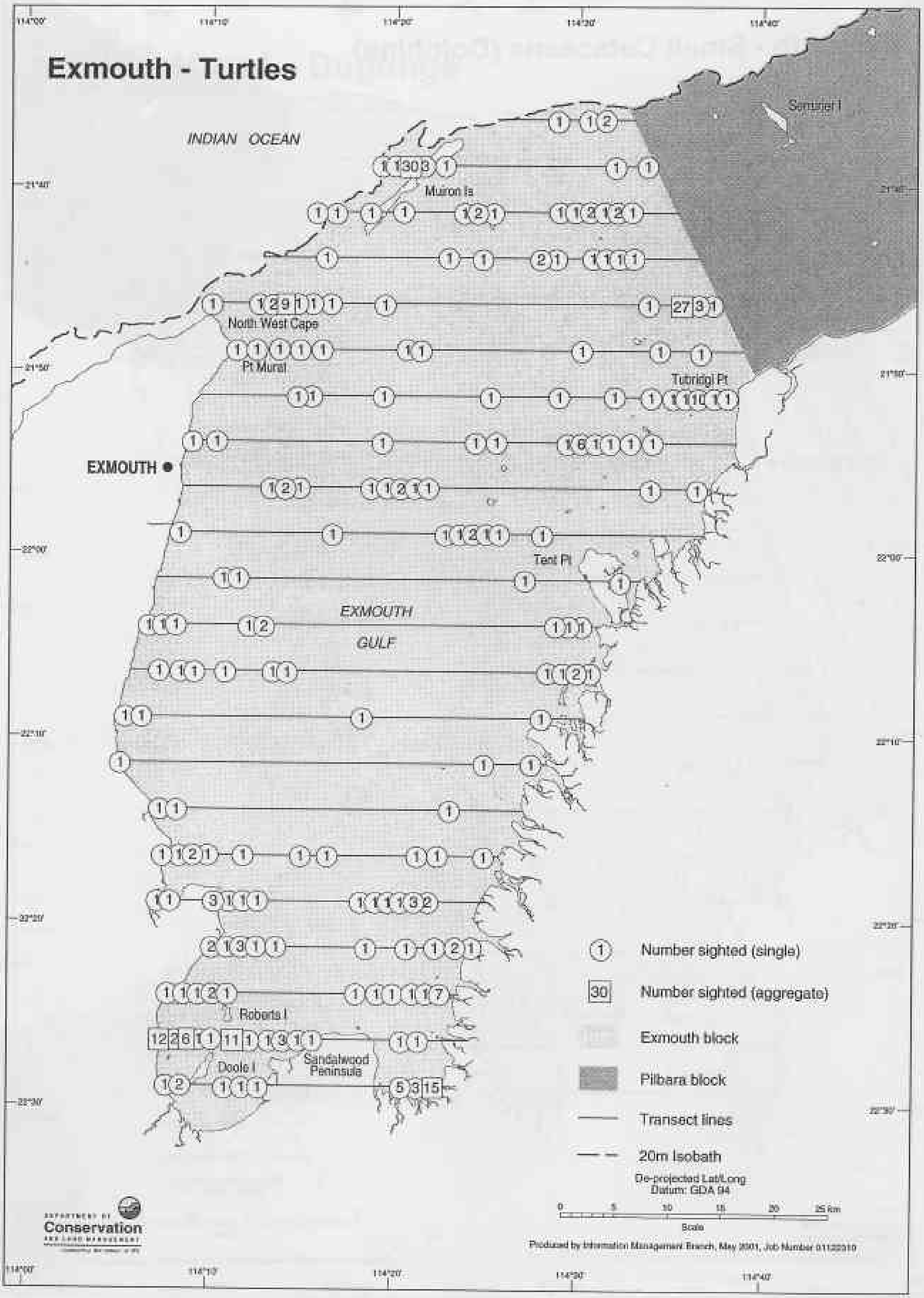

Figure 5. Pilbara 2000 Survey: Exmouth Block Transects and Turtle Sightings.

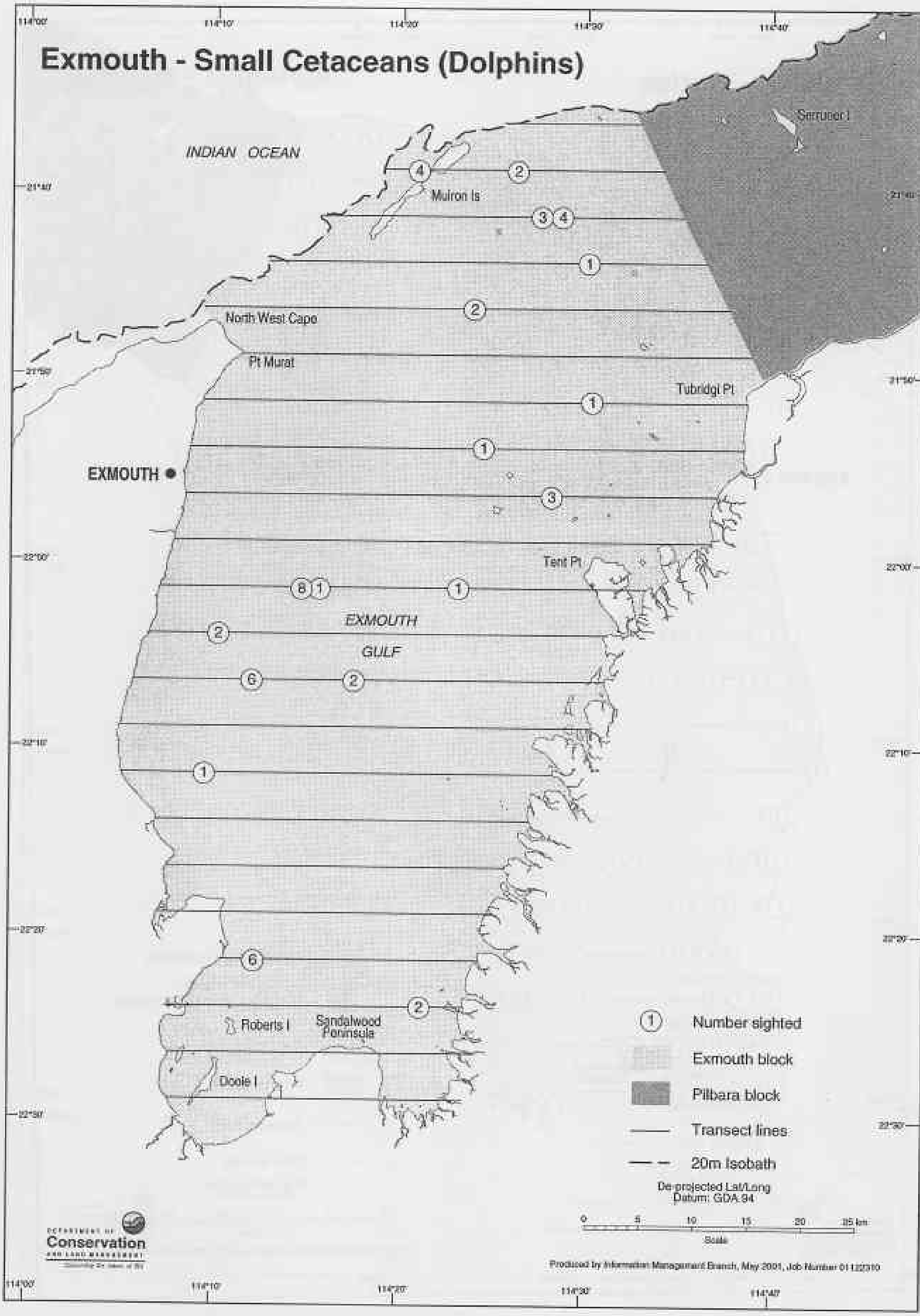

Figure 6. Pilbara 2000 Survey: Exmouth Block Transects and Small Cetacean (Dolphin) Sightings.

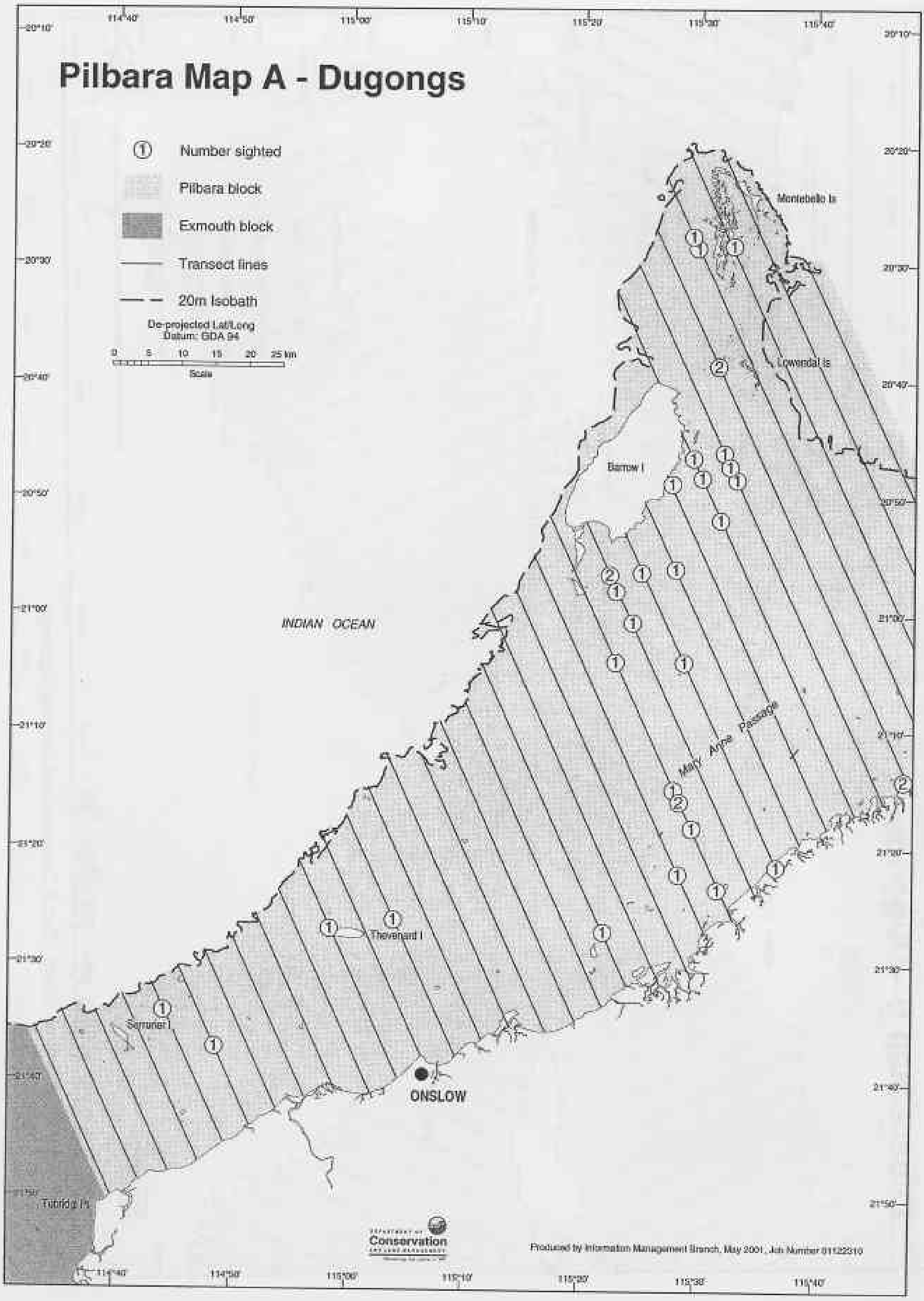

Figure 7. Pilbara 2000 Survey: Pilbara - Part A Transects and Dugong Sightings.

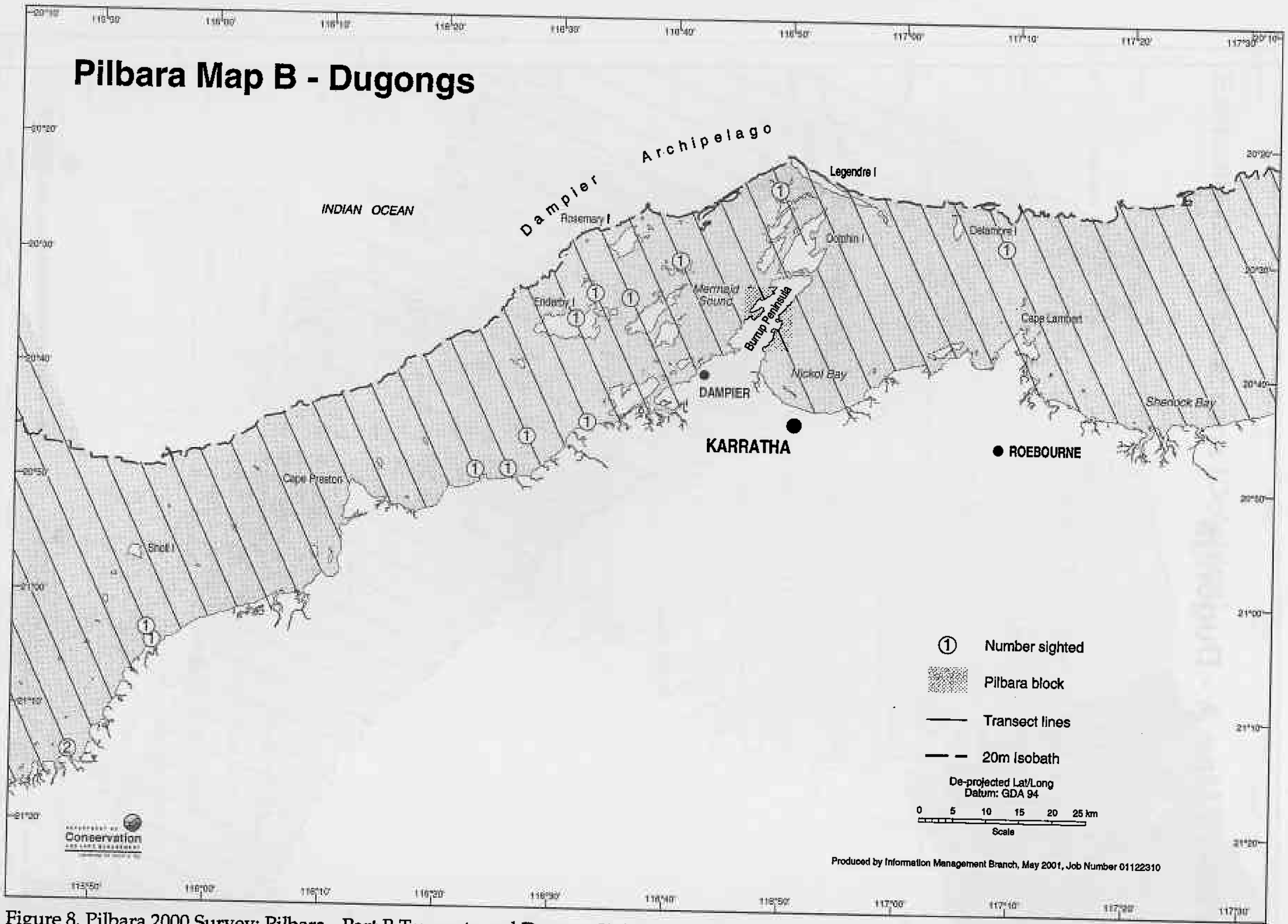

Figure 8. Pilbara 2000 Survey: Pilbara - Part B Transects and Dugong Sightings.

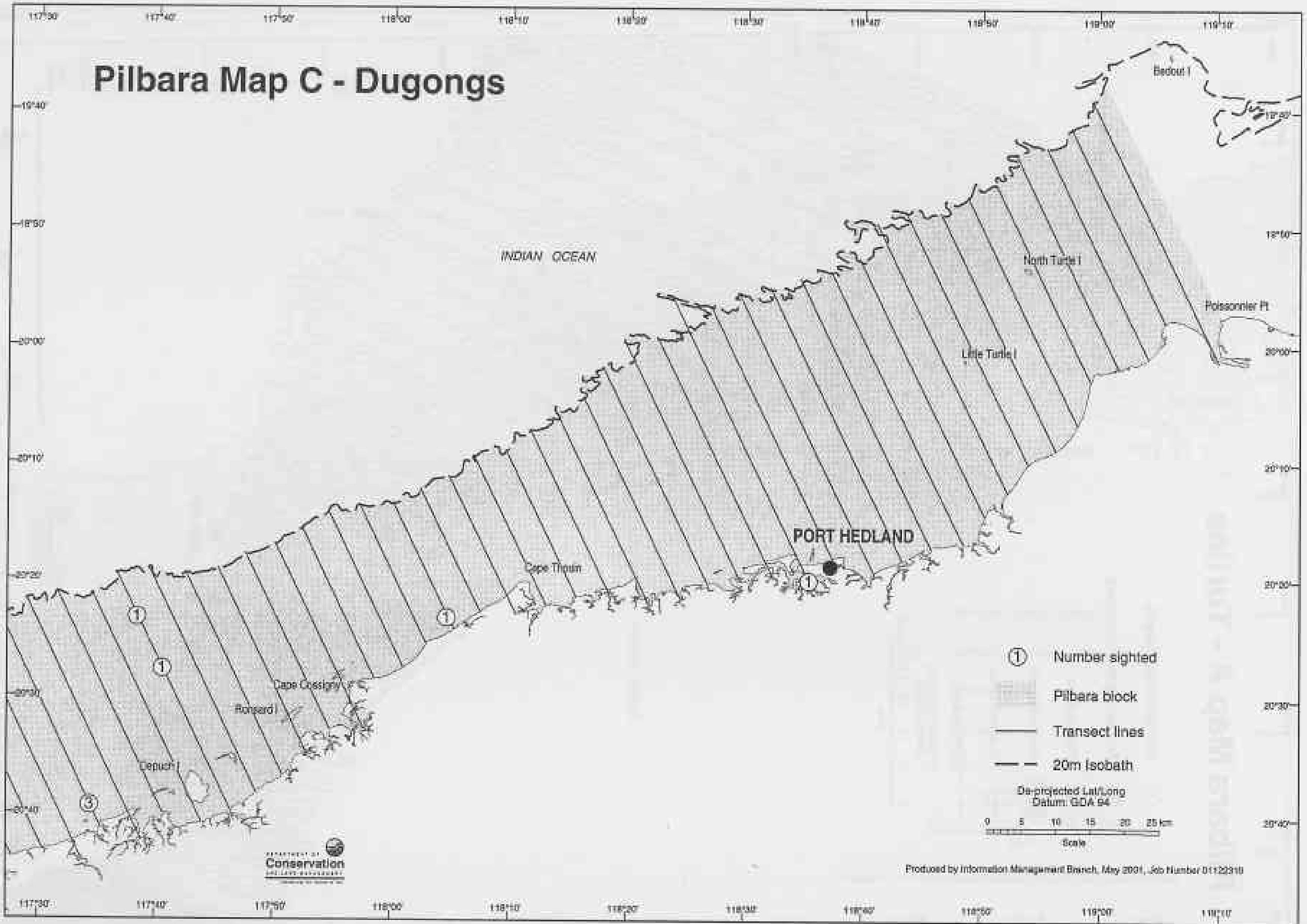

Figure 9. Pilbara 2000 Survey: Pilbara - Part C Transects and Dugong Sightings.

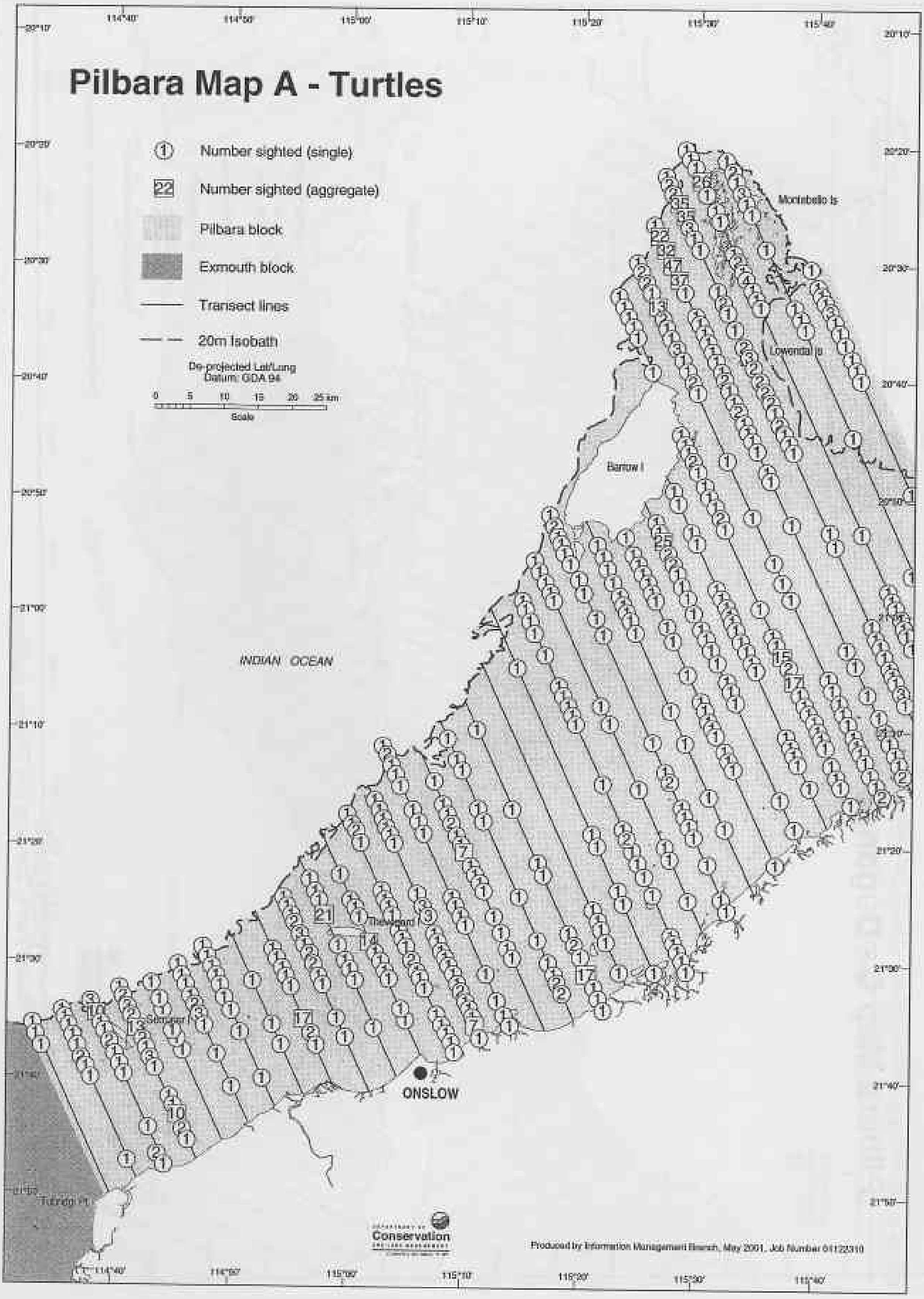

Figure 10. Pilbara 2000 Survey: Pilbara - Part A Transects and Turtle Sightings.

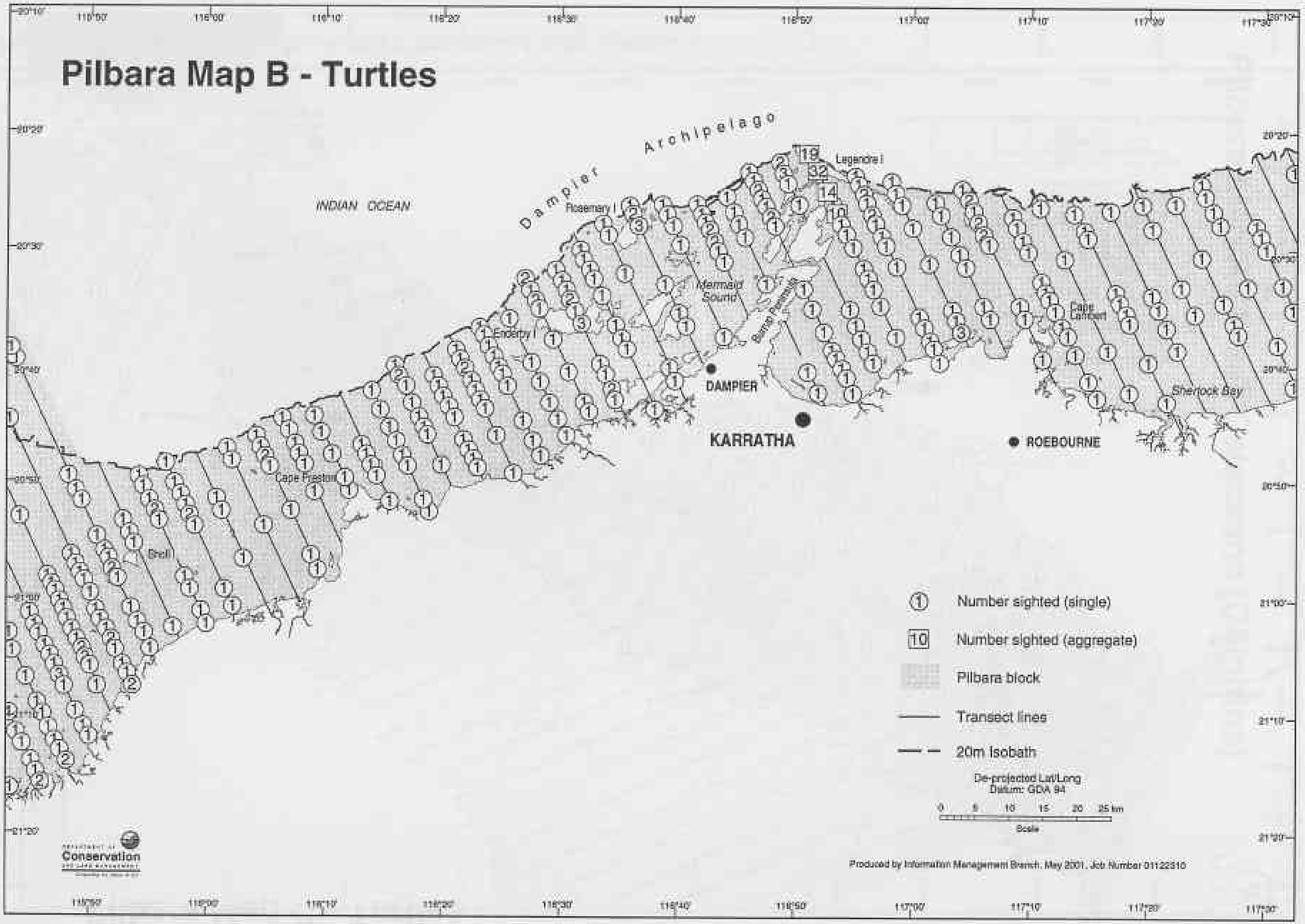

Figure 11. Pilbara 2000 Survey: Pilbara - Part B Transects and Turtle Sightings.

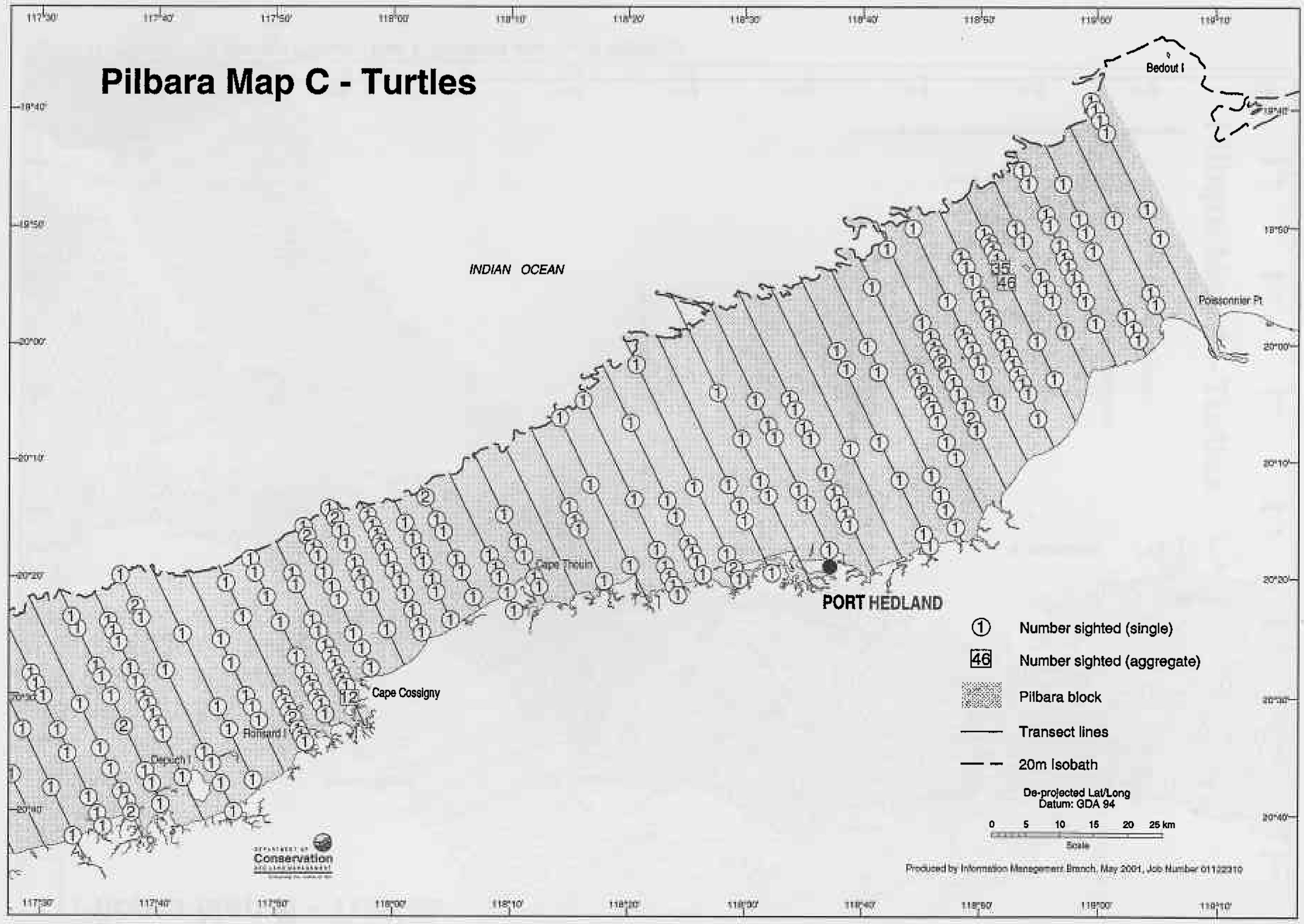

Figure 12. Pilbara 2000 Survey: Pilbara - Part C Transects and Turtle Sightings.

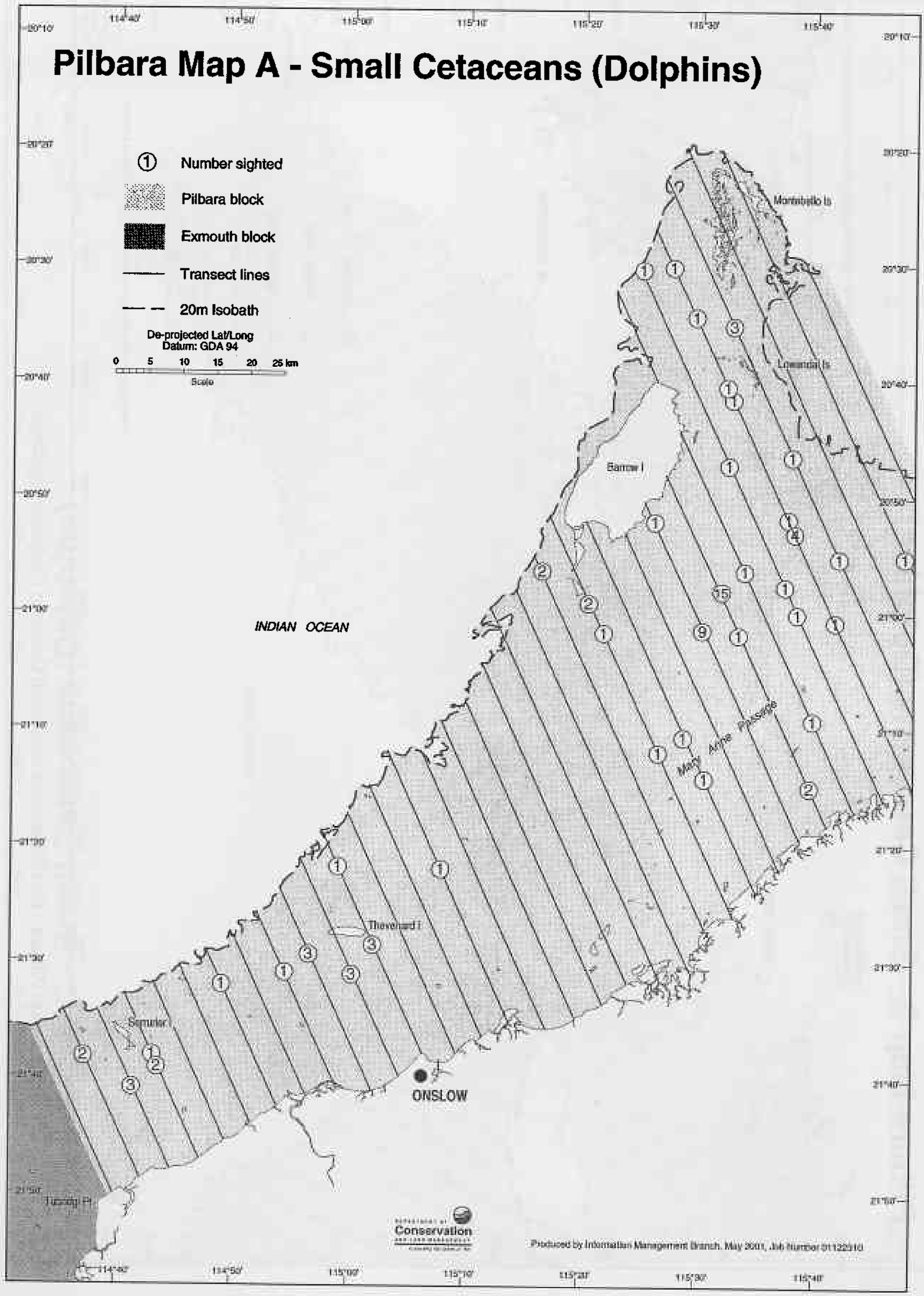

Figure 13. Pilbara 2000 Survey: Pilbara - Part A Transects and Small Cetacean (Dolphin) Sightings.

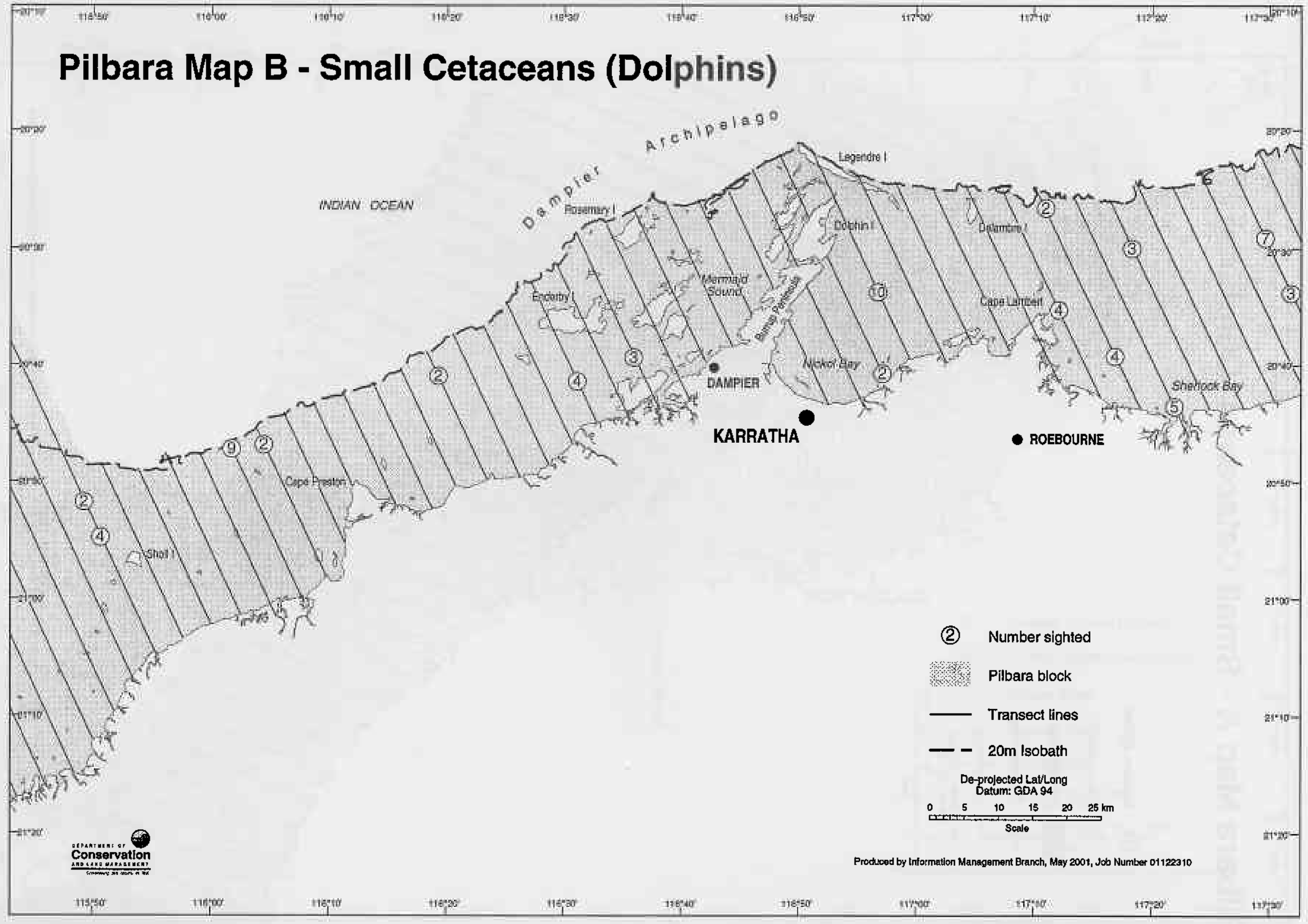

Figure 14. Pilbara 2000 Survey: Pilbara - Part B Transects and Small Cetacean (Dolphin) Sightings.

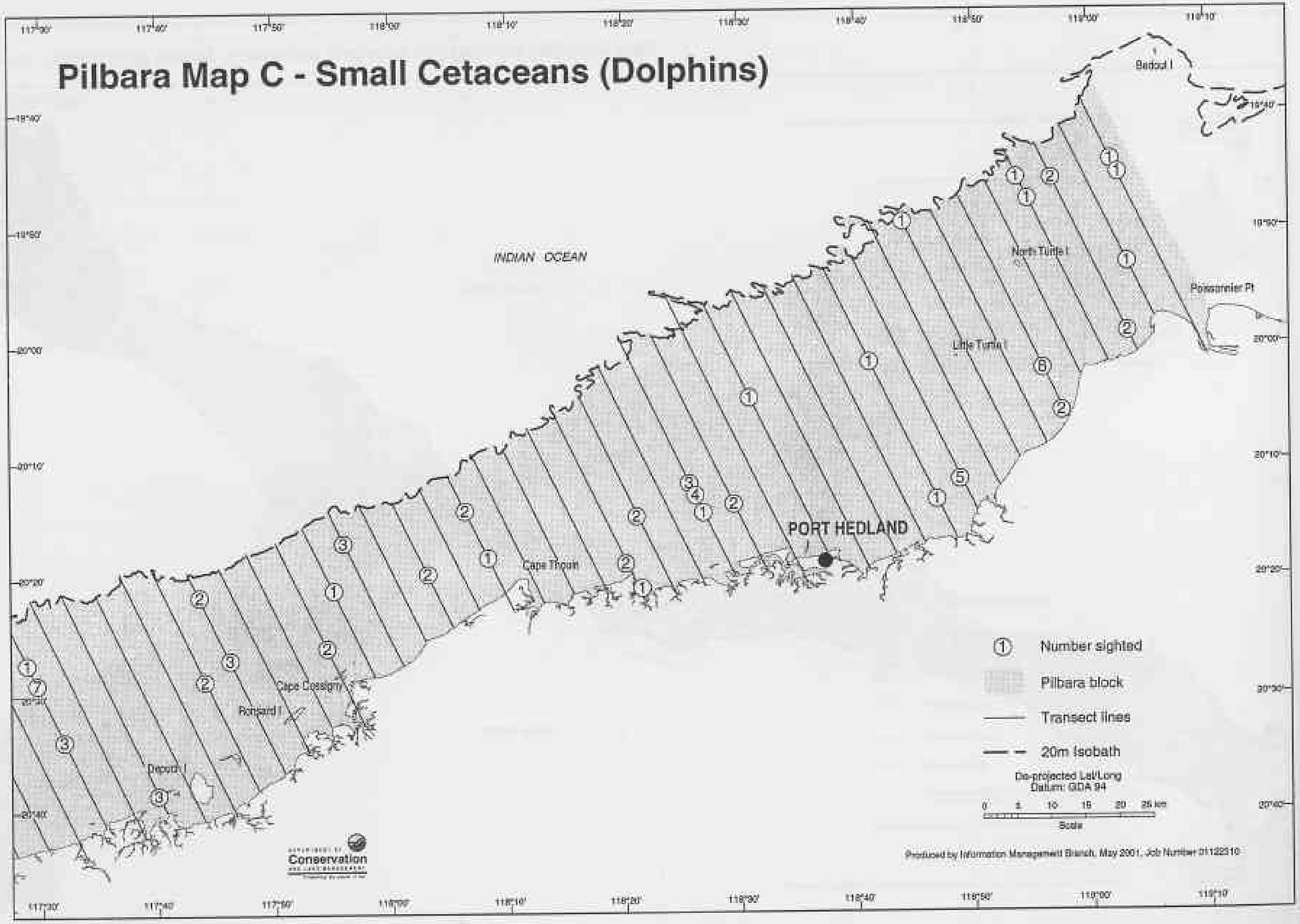

Figure 15. Pilbara 2000 Survey: Pilbara - Part C Transects and Small Cetacean (Dolphin) Sightings.

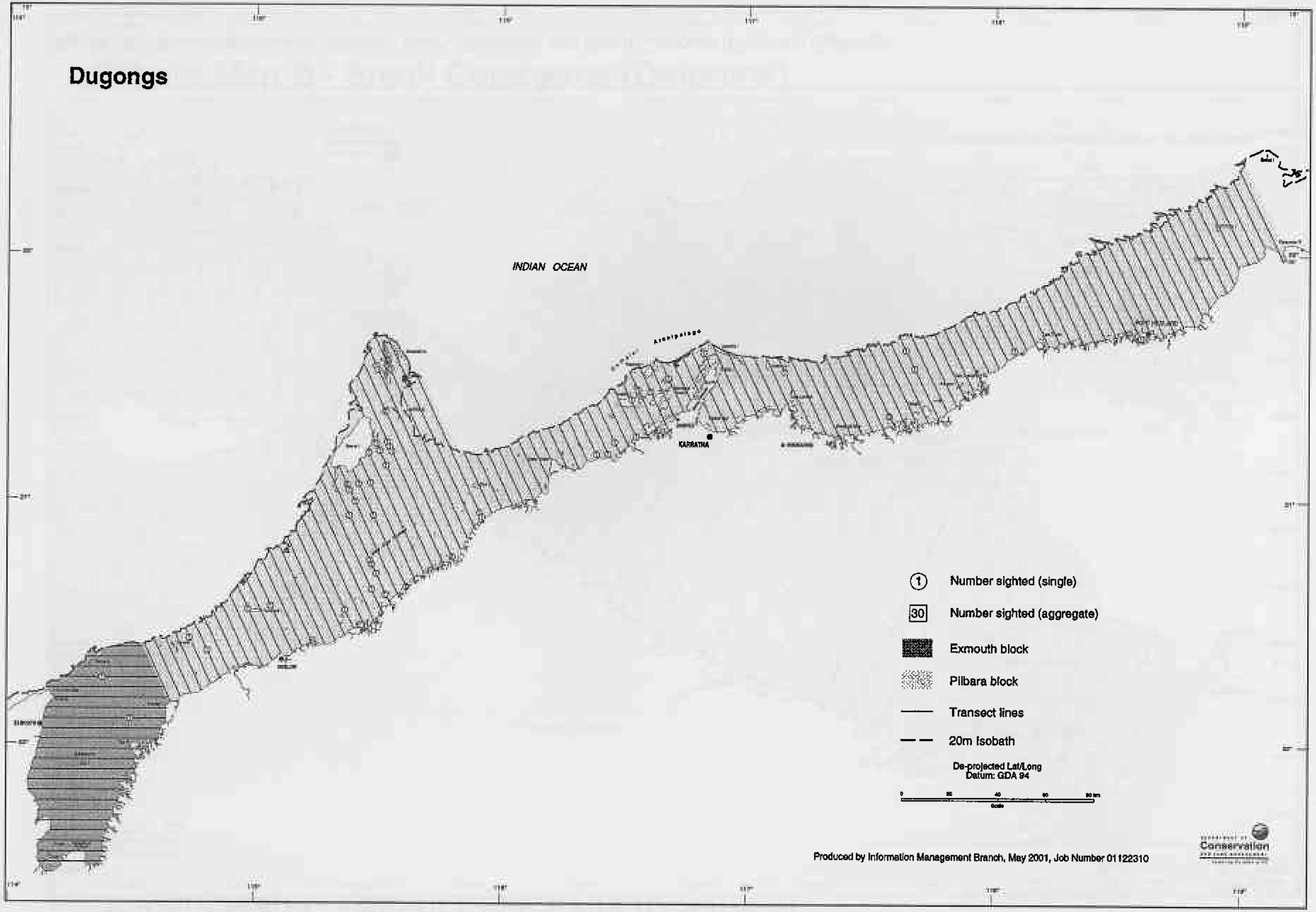

Figure 16. Pilbara 2000 Survey: Combined Transects and Dugong Sightings Data.

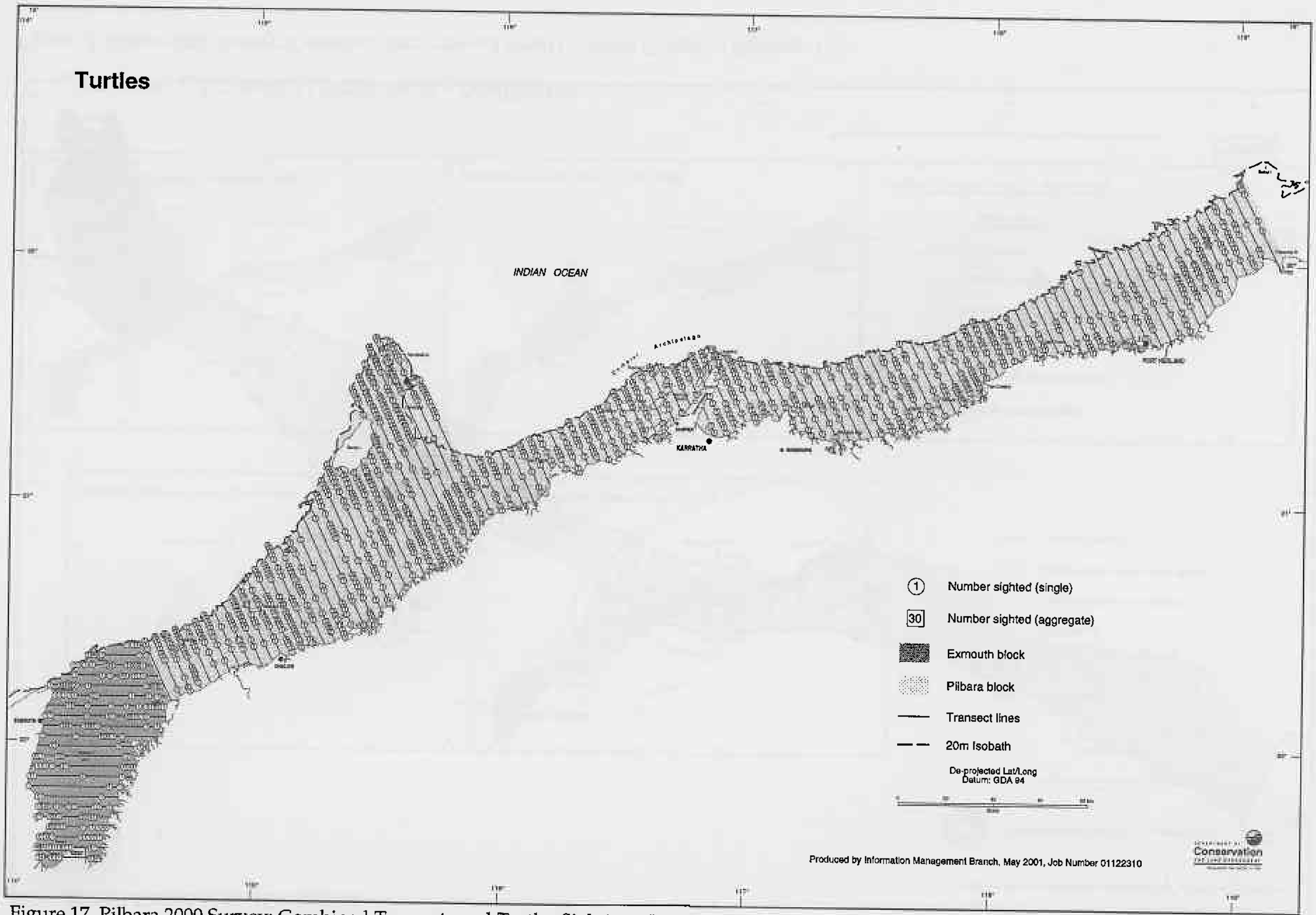

Figure 17. Pilbara 2000 Survey: Combined Transects and Turtles Sightings Data.

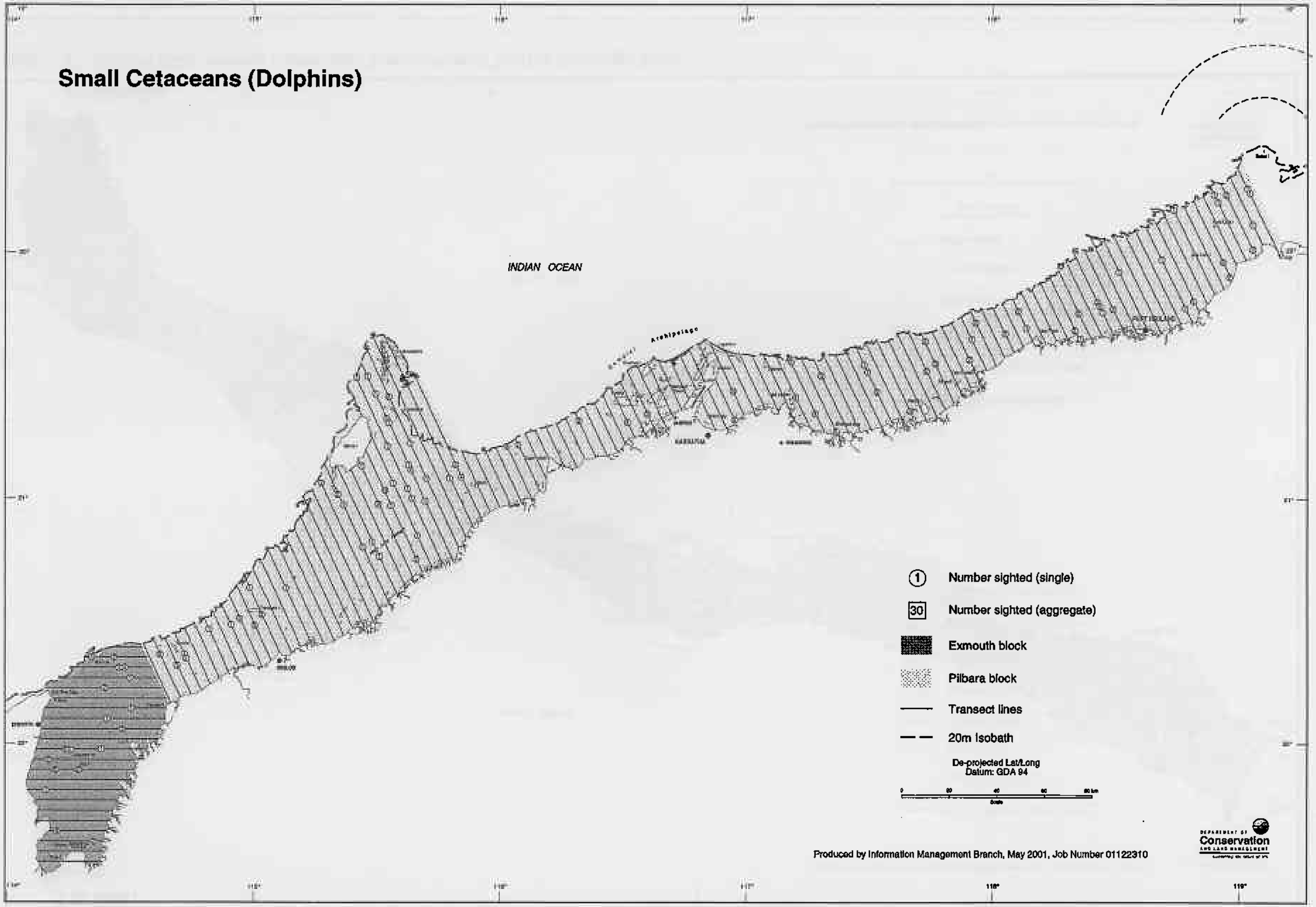

Figure 18. Pilbara 2000 Survey: Combined Transects and Small Cetacean (Dolphin) Sightings Data.

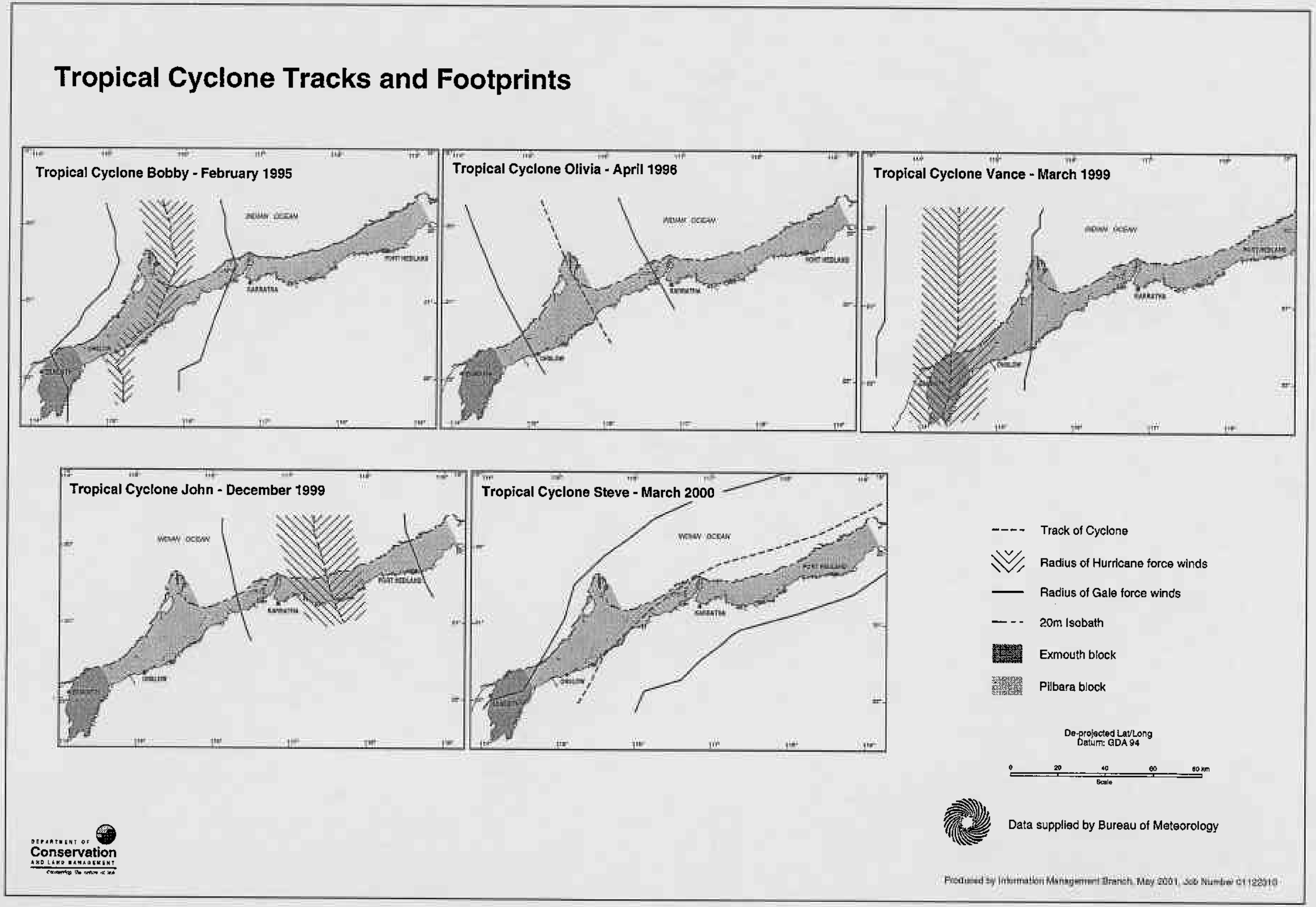

Figure 19. Pilbara 2000 Survey: Tropical Cyclones - Tracks and the Resulting 'Footprints' Affecting the Exmouth and Pilbara Coastal Waters Area - February 1995 to March 2000.