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Priority areas for conservation of Western Australian coastal fishes: A comparison of hotspot, biogeographical and complementarity approaches

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Abstract

Western Australia has an extensive coastline ranging from the tropical north to the temperate south, with a high diversity of neritic marine fishes. Distribution data of 1855 neritic fish species were used to compare a range of methods for identifying priority areas for their conservation. Species richness and endemism richness hotspots, biogeographic zoning and complementarity analysis were tested for their efficiency at representing the total suite of species. The hotspot approaches demonstrated low efficiency, as the sections of coastline selected were grouped together in isolated geographic locations and relatively few of the total suite of neritic fish species were represented. Biogeographic zoning divided the coast of Western Australia into six regions, and as such, priority areas were selected around the entire coastline, which resulted in fairly high levels of efficiency. However, the complementarity analysis proved to be the most efficient method, as >95% of all neritic fish species could be represented in six, appropriately located, 100 km long sections of coastline. Complementarity analysis indicated a total of 26 priority areas for neritic fish conservation, which were spread around the entire coast of Western Australia. However, as current marine conservation measures in Western Australia are focused on the west and northwest coasts, this study highlighted the need for marine conservation efforts to be extended to cover the north and south coasts.

Keywords: Species richness; Endemism; Iterative selection; Biogeography; Marine protected areas

1. Introduction

Western Australia is the largest state in Australia, with a complex coastline spanning over 23° of latitude, which ranges from tropical in the north to warm temperate in the south (Fig. 1). There is a corresponding array of marine habitats, including mangals, extensive mud flats, coral reefs, sandy beaches, rocky shores, seagrass meadows and kelp beds. Although the waters off Western Australia are nutrient poor and low in productivity (Hanson et al., in press), they have been identified as the second richest multi-taxon (coral, fishes, lobsters and molluscs) centre of endemism in the world (Roberts et al., 2002). There are approximately 3000 marine fish species (including a number of undescribed species) known to occur in the waters off Western Australia (Hutchins, 2001). The relatively comprehensive data on the distributions of these fishes in coastal waters provided the opportunity to test the efficiency of some marine reserve selection approaches to identify broadscale priority areas for their conservation.

Historically, selection of marine reserves has been opportunistic or ad hoc (Leslie et al., 2003), with public pressure, politics and the need to solve user conflicts often influencing the selection process (Kelleher and Kenchington, 1992; Hockey and Branch, 1997; Roberts, 2000; Beger et al., 2003). However, in order to conserve

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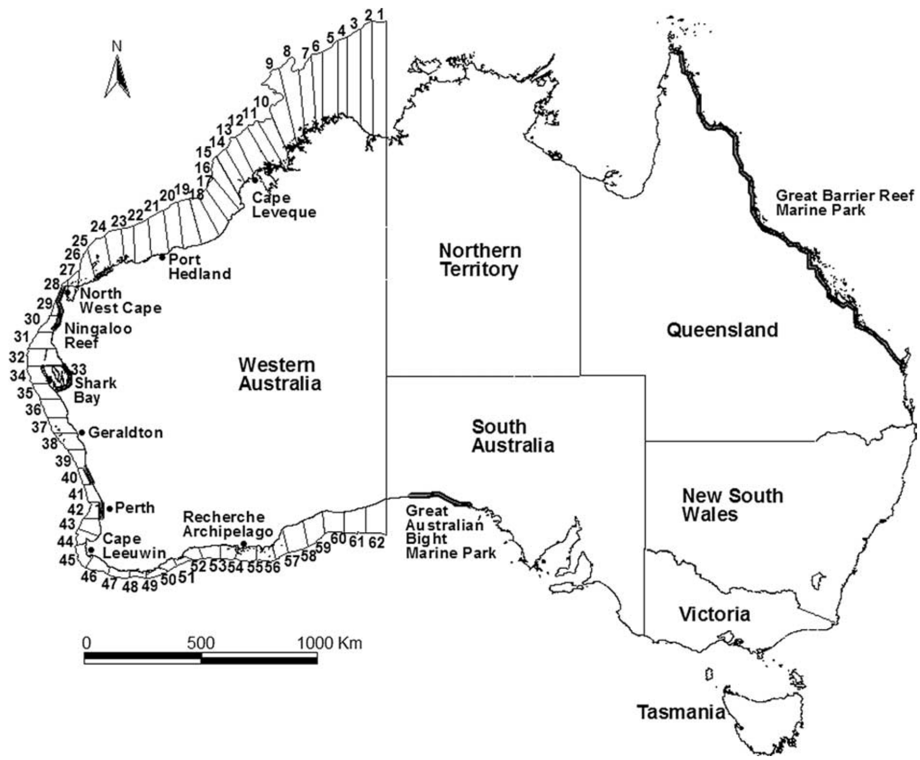

Fig. 1. Map of Australia with the states labelled, showing the 62 × 100 km sections off the Western Australian coast, extending to the 200 m isobath; the Western Australian marine protected areas and the Great Australian Bight and Great Barrier Reef Marine Protected Areas (shown as shaded sections of coastline); plus the locations mentioned in the text.

biological diversity and make the best use of the limited resources available for conservation, the reserves selected should be as representative as possible (Pressey et al., 1993; Stewart et al., 2003). This has resulted in the evolution of a range of systematic methods (e.g., hotspots, biogeography, iterative selection and mathematical solutions) to develop reserve systems in an efficient and scientifically defensible manner (Margules and Pressey, 2000; Leslie et al., 2003). Although mathematical solutions for reserve selection, based on simulated annealing (Possingham et al., 2000), have been increasing in popularity and have been used for the recent rezoning of the Great Barrier Reef Marine Park (Lewis et al., 2003), and for reserve design and selection in the Channel Islands (Airame et al., 2003) and the Gulf of California (Sala et al., 2002), the major cited limitation of this approach is the extensive and continuous data required to run the programs (Possingham et al., 2000). The nature of the data available for this study was not suited to such mathematical selection techniques, but it was appropriate to be used in hotspot, biogeographic and iterative methods.

'Hotspot' analysis identifies reserve locations based on maxima of species richness or endemism (Prendergast et al., 1993; van Jaarsveld et al., 1998; Beger et al., 2003). It is argued that this method can be inefficient, as hotspots of species richness and endemism do not usually overlap (Prendergast et al., 1993; Williams et al., 1996; Turpie et al., 2000). Theoretically, marine reserves located according to biogeographic zones should ensure representativeness, as the suites of species within each zone are different (Day and Roff, 2000; Roberts et al., 2003; Lourie and Vincent, 2004). However, while the major biogeographic zones are relatively well known, fine-scale distinctions can be difficult to determine and, if reserves are not selected in combination with other knowledge, species with limited distributions may be omitted. Another disadvantage of these two methods is that they do not address the question of efficiency. Efficiency and minimisation have been addressed in terrestrial reserve design theory because of the need to reduce the area in reserves in response to the limited financial resources available to purchase land for conservation, and the number of competing land uses (Pressey et al., 1993). Minimisation is also relevant in marine systems as, although the ocean is a common property resource and therefore does not need to be purchased for conservation, there are many different, and conflicting, economic and social uses. Reducing the conflict between these differing stakeholders can be assisted by having the reserve system as efficient as possible, and therefore minimising the area in reserves, while still meeting conservation targets.

Efficiency is a key component of iterative marine reserve selection, which aims to minimise the area encompassed by the reserve while still protecting the target group of species, habitat types or other features (Pressey and Nicholls, 1989; Pressey et al., 1993; Leslie et al., 2003). Iterative selection is based on complementarity, whereby, once an initial reserve has been identified, all other sites must be selected to complement the previous ones, and thus replication of reservation features does not occur (Vane-Wright et al., 1991; Pressey et al., 1996). This has the advantage of being relatively rapid, operating in an intuitive manner (Leslie et al., 2003) and working well with simple binary data (e.g., presence/absence) (Possingham et al., 2000), but the selection initially generates only one 'optimal' answer and practical problems in reserve design may render an 'optimal' solution not feasible (Leslie et al., 2003). However, it is possible to compare alternative solutions with iterative process selection by altering the attributes and criteria being analysed in the light of the initial results.

The question of the 'best' or most efficient method for identifying marine reserve locations or for highlighting areas of conservation importance is still the subject of debate. Beger et al. (2003) tested the relative efficiencies of hotspots, biogeographically stratified hotspots, and complementarity analysis in a localised area using presence/absence data for fishes and corals. At a broader scale, Turpie et al. (2000) applied biogeography, species richness hotspots and complementarity analysis to presence/absence data for coastal fishes in South Africa. However, they did not directly compare the efficiencies of the range of approaches. The present study aimed to test three reserve selection methods, hotspots of species richness and endemism, biogeography, and complementarity analysis, for their efficiency at identifying areas of conservation importance for neritic fishes around the Western Australian coastline. The second objective was to use the most efficient of these methods to identify and prioritise broadscale areas of conservation importance for neritic fishes in Western Australia.

2. Methods

2.1. Development of the database

Although there were relatively extensive data on Western Australian fishes, these data were in a number of formats and located in different sources. In order to create an initial database of fishes known to occur off Western Australia, two primary data sources, namely the Western Australian fish list of Hutchins (2003) and the recently updated *Zoological Catalogue of Australia* (Hoese et al., in press; Paxton et al., in press) were combined. Inconsistencies between the two sources were checked for validity prior to data being included in the database. Records of species were considered valid when there were at least three museum records for that species in the same general location in Western Australia, ascertained through the *OzFishNet* (Australian Museum, 2003). Synonym queries between the two lists were checked against *Catalogue of Fishes* (Eschmeyer, 2003) and nomenclature changes made or species removed from the database as necessary. When a species was incompletely classified it was not included in the database. The geographic affiliation, endemism, ecology and distribution of each fish species around Western Australia were added to the database. This information was obtained primarily from the *Zoological Catalogue of Australia* (Hoese et al., in press; Paxton et al., in press), with additional information obtained from *FishBase* (Froese and Pauly, 2003) and museum records (Australian Museum, 2003). As our study was restricted to neritic (coastal and shelf) species, all non-neritic (i.e., oceanic and slope species), introduced and freshwater species were removed. Neritic species that were found only at Western Australia's offshore islands and reefs, such as Rowley Shoals, Scott Reef and Ashmore Reef, were also removed, as these islands were outside the study area and the species assemblages are not closely affiliated with continental neritic species (Hutchins, 2001).

The coastline of Western Australia was divided into 62×100 km sections, determined by hand digitising 1:250,000 km scale bathymetry data using ARCVIEW GIS software. Section boundaries were extended from the coast out to the 200 m isobath following the shortest possible distance. Where boundary lines intercepted island chains, they were shifted to keep island chains in the same section (Fig. 1). A binary database was created using the 62 sections and the species distribution information, with each fish being recorded as present or absent in each coastal section. The database was checked further for vagrant species with the aim of removing any Indo-Pacific and global species that were represented by a single record in a single location. Their distributions were checked against the *Zoological Catalogue of Australia* (Hoese et al., in press; Paxton et al., in press) and against all Australian museum records (Australian Museum, 2003).

2.2. Species richness and endemism analyses

The number of neritic fish species present in each coastal section and the contribution of Indo-Pacific, Australian endemic, Western Australian endemic and 'other' species (global species and species with distributions extending beyond the Indo-Pacific region) were determined. To determine hotspots, the sections were ranked according to the total number of species and the total number of endemics.

2.3. Biogeographic analysis

Cluster analysis (using Bray–Curtis similarity) and multidimensional scaling were performed, using the PRIMER v 5.2 package (Clarke and Gorley, 2001), to determine biogeographic zones around Western Australia. To check the adequacy and consistency of the two methods, the cluster analysis was overlaid on the multidimensional scaling plot at the 60% and 80% levels of similarity. Priority areas for conservation were selected from both the centres and the northern edges of biogeographic zones, resulting in two suites of sections. These were compared as there is some debate concerning the most efficient approach (Lesica and Allendorf, 1995; Hockey and Branch, 1997; Roberts et al., 2003).

2.4. Complementarity analysis

Complementarity analysis is an iterative selection technique that is designed to select the minimum set of sites necessary to protect a suite of species (Pressey et al., 1993). The complementarity analysis used in this study was based on a rarity algorithm which preferentially selected sections containing rare species (Turpie et al., 2000). Each section of the Western Australian coast was initially assigned a rarity value using Rebelo and Siegfried's (1992) rarity algorithm:

$$\text{Rarity} = \sum k/a_i,$$

where k is the total number of unreserved sections and a_i is the number of unreserved sections containing the ith species. The section with the highest summed rarity value was nominally reserved and removed from the matrix, together with all of the species that were present in that section. The summed rarity value for each remaining section was recalculated and the next highest section removed along with its associated species. The process was continued until all species were reserved. The complementarity analysis was run on the complete database, as well as on Western Australian endemics and on total endemics (Australian and Western Australian endemics).

2.5. Comparison of methods

Efficiency of reserve selection has been defined as $E = 1 - (X/T)$, where E is the efficiency of the sites selected, X is the number of sites needed to meet the conservation target and T is the total number of sites (Pressey and Nicholls, 1989). For this study, it was not possible to compare directly the efficiency of the approaches using this formula, as the conservation targets of the approaches were different (biogeographic approaches were focussed on protecting representative biota from each zone, while the other approaches had the conservation target of protecting all species). To overcome this, the efficiencies of the selection methods were compared by analysing the cumulative number of species represented in a predetermined number of sections. As the biogeographic approaches only selected six sections of the coastline in total, only the six highest ranking sections from the hotspot and complementarity approaches were used in this analysis. For the complementarity analyses run using endemic species only, the

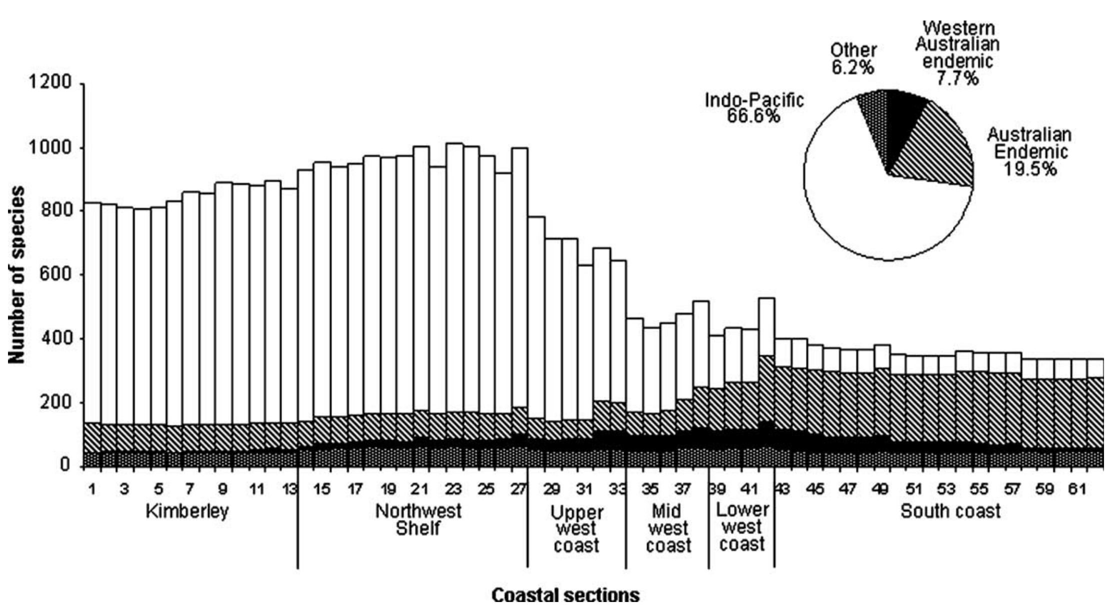

Fig. 2. Species richness and geographic affiliation of fish species in each of the 62 sections of the Western Australian coast ($n = 1855$ species), with inset showing the percentage of each geographic affiliation within the total neritic fish fauna of Western Australia. (Shading in the bar graph corresponds with that in the inset.)

Table 1
Comparison of the Western Australian coastal sections selected as areas of conservation importance by the different approaches used, and the cumulative percentage of fish species represented (n = 1855 species). As the biogeographic approach used resulted in a total of six sections being selected, for ease of comparison, the top six coastal sections were used for hotspots of species richness, endemism richness and complementarity analysis. Numbers in bold indicate the percentage of total fish species reserved by these methods

Species richness hotspots		Endemism hotspots		Biogeography (centre of zones)		Biogeography (edge of zones)		Complementarity analysis (Western Australian endemics)		Complementarity analysis (all endemics)		Complementarity analysis (all species)	
Section	%	Section	%	Section	%	Section	%	Section	%	Section	%	Section	%
23	54.6	42	28.5	6	45.0	1	44.4	42	28.5	42	28.5	27	53.9
24	55.0	44	29.4	20	58.5	13	50.9	32	50.0	27	71.5	1	69.3
21	59.1	45	29.7	30	70.5	27	70.9	27	72.6	62	75.3	42	87.0
27	67.1	49	30.8	36	75.8	33	76.7	21	84.7	21	87.3	21	90.8
18	68.1	43	30.8	40	82.3	38	82.3	23	85.7	32	88.4	62	94.5
25	**68.6**	54	**31.7**	52	**88.8**	42	**89.6**	49	**87.7**	1	**95.6**	23	**95.5**

total numbers of all fish species represented in the top six sections were used to allow comparison with the other approaches.

3. Results

3.1. Species richness and endemism

There was a total of 1855 species comprising the Western Australian neritic fish fauna, of which, 66.6% were Indo-Pacific species, 19.5% were Australian endemics, 7.7% were Western Australian endemics and 6.2% were other species with global distributions or distributions which extended beyond the Indo-Pacific region (Fig. 2). Although species richness generally decreased from north to south, there was a slight increase from the Kimberley coast (sections 1–13) to North West Cape (section 27) (Fig. 2). The most dramatic decline in species richness occurred along the west coast, with numbers of species declining from 999 species at the northern extent of Ningaloo Reef (section 27) to 382 species at Cape Leeuwin (section 45). While species richness along the south coast was relatively stable (334–381 species), there were generally fewer species near the South Australian border.

Indo-Pacific species followed the same trend as the total fish fauna, with significantly higher numbers of species in the northern sections (840 species, Dampier Archipelago, section 23) than southern sections (61 species, Great Australian Bight, section 60) (Fig. 2). Total endemic species (Australian and Western Australian) had an opposite pattern to the Indo-Pacific species, with higher numbers of species in the south than the north (Fig. 2). However, Western Australian endemics did not follow this trend, with the number of species peaking on the lower west coast (section 42, Perth, 78 species), and decreasing both northwards and southwards from this section. The species richness 'hotspots' all occurred on the northwest coast, while the endemism richness 'hotspots' were all on the south and south west coasts (Fig. 2, Table 1).

3.2. Biogeography

Both the cluster analysis and multidimensional scaling (Fig. 3) revealed a major biogeographic division at Shark Bay (section 33), dividing the Western Australian neritic fish fauna into two distinct groupings, a northern tropical fauna and a southern temperate fauna. In more detail, at the 60% similarity level, the northern fauna was separated by Northwest Cape, creating an upper west coast section encompassing Shark Bay and Ningaloo Reef (sections 28–33). The northern coast was further divided at 80% similarity at Cape Leveque, resulting in a Kimberley region and a Northwest Shelf

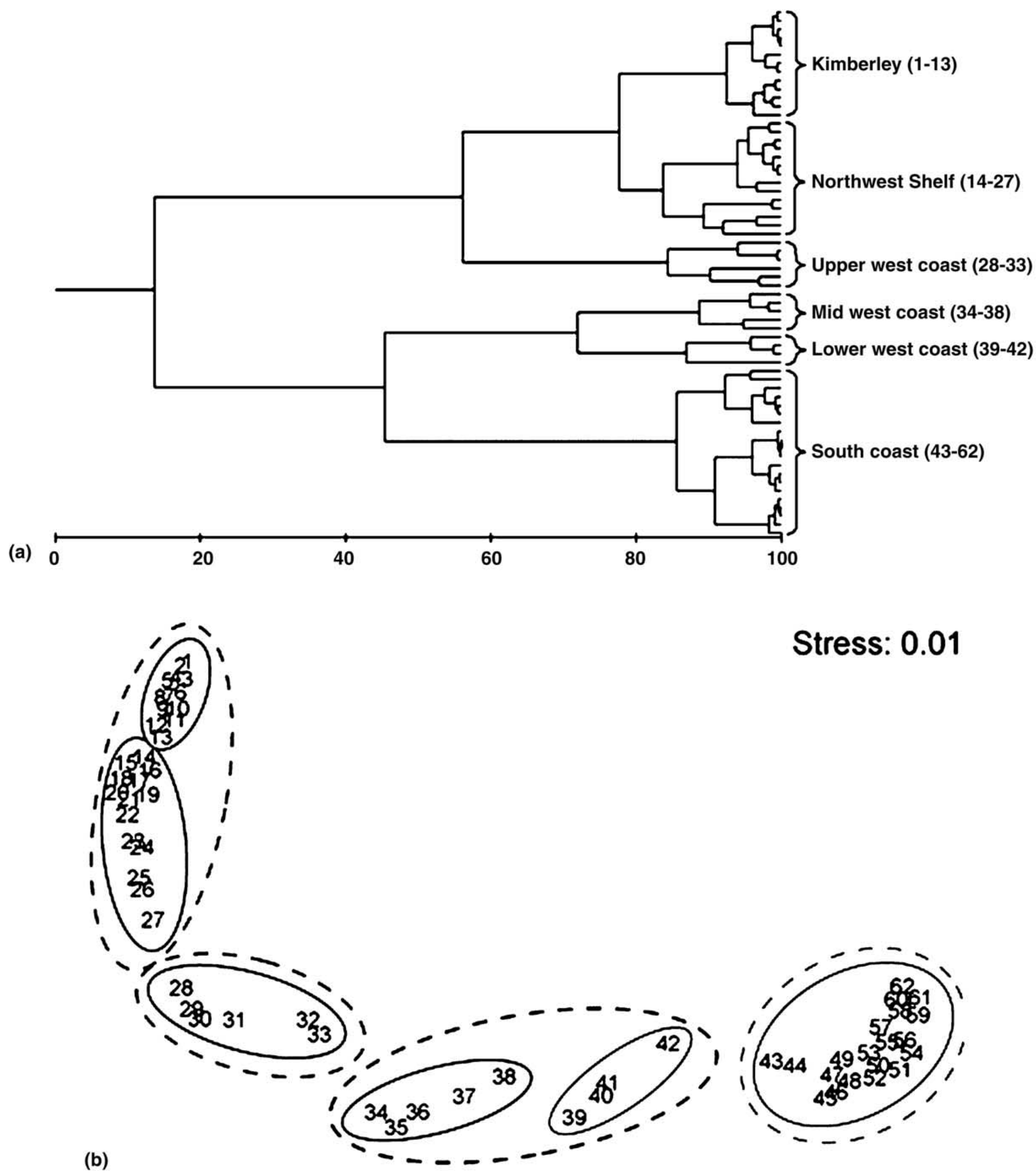

Fig. 3. (a) Bray–Curtis similarity dendogram of the 62 Western Australian coastal sections, based on fish species composition in each section. Sections are ordered from north to south, with section 1 (Northern Territory border) at the top of the dendogram and section 62 (South Australian border) at the bottom. Labels are of coastal regions (consisting of sections grouped together at >80% similarity). (b) Two dimensional multidimensional scaling plots of fish composition of the 62 coastal sections with superimposed clusters from Bray–Curtis similarity analysis at 60% (broken line) and 80% (solid line) similarity levels.

region. The temperate fauna had a major division south of Perth (section 42) resulting in a large, continuous south coast grouping. Between Perth (section 42) and Shark Bay (section 33), the fauna divided into mid and lower west coast groupings at Geraldton (section 37).

Using the centres and northern edges of biogeographic zones (at 80% similarity), two suites of sections were selected (Table 1). Both approaches were representative of the entire coastline but, because of the greater number of biogeographic zones on the west coast, more sections were selected there than on the north or south coasts. It should be noted that only the centre approach selected a south coast section due to the northerly bias of the biogeographic zone edge approach.

Table 2
Complementarity analysis performed on all Western Australian neritic fishes (n = 1855 species) indicating order of section reservation, the total number of species contained in each section, the number of additional species each section brings to the complementarity analysis, and the cumulative number of species represented

Sections	Total number of fish species in section	Number of additional fish species	Cumulative number of fish species
27	999	999	999
1	823	286	1285
42	528	328	1613
21	1001	71	1684
62	339	69	1753
23	1012	19	1772
32	685	20	1792
25	973	8	1800
7	858	16	1816
12	898	9	1825
15	953	3	1828
49	381	3	1831
45	382	3	1834
17	950	4	1838
57	355	4	1842
34	467	2	1844
2	820	1	1845
3	809	1	1846
6	834	1	1847
24	1002	1	1848
26	919	1	1849
29	713	1	1850
46	369	1	1851
9	889	2	1853
13	867	1	1854
37	479	1	1855

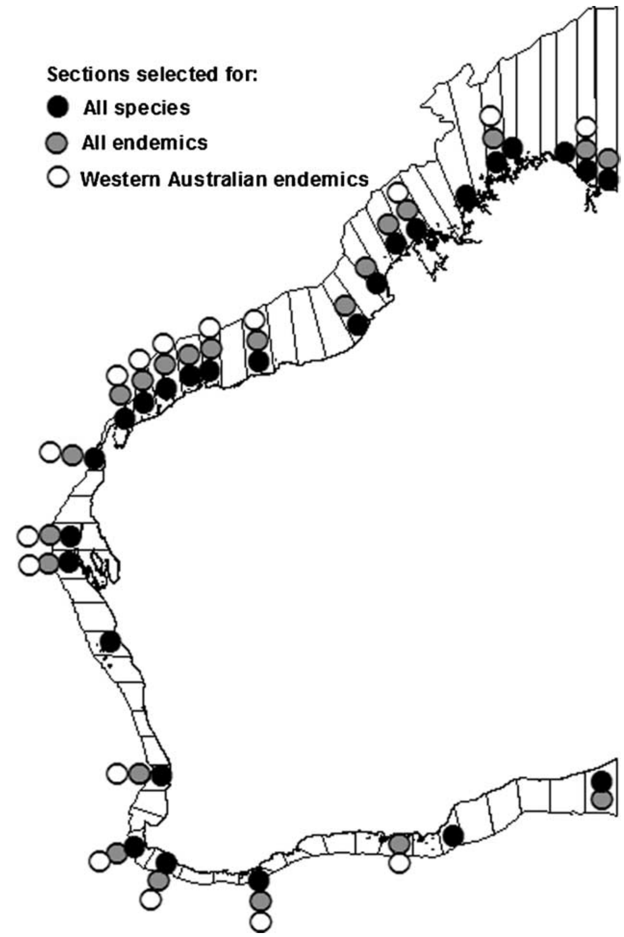

Fig. 4. Map of Western Australian coastline showing sections selected by the complementarity analyses using all species (black circles), all endemic species (grey circles) and Western Australian endemic species only (white circles).

3.3. Complementarity analysis

Complementarity analysis revealed that, theoretically, all of the 1855 Western Australian neritic fish species could be represented in 26×100 km sections of coast (Table 2, Fig. 4). The sections with the highest summed rarity values were section 27 (containing Exmouth Gulf, North West Cape and the northern extent of Ningaloo Reef), section 1 (adjoining the Northern Territory border), section 42 (Perth region, including Rottnest Island), section 21 (Northwest Shelf around Port Hedland), section 62 (adjoining the South Australian border) and section 23 (Dampier Archipelago). As more sections were reserved, the number of additional species protected decreased with each iteration, with the last 16 sections protecting fewer than five additional species per section. However, these sections were not necessarily unimportant, as the additional species protected by twelve of these sections were Western Australian and Australian endemics with limited ranges.

When the complementarity analysis was performed on total endemics (Australian and Western Australian, n = 504 species), 22×100 km sections of coast were required to represent all the endemic species (Table 3, Fig. 4). As with the complementarity analysis on all species, the sections were selected around the entire coast, although, of the sections with the highest rarity values, only one was selected on the south coast (section 62, South Australian border), with all the others occurring north of Perth. To represent just Western Australian endemics (n = 142 species), 16×100 km sections were selected around the coast (Table 3, Fig. 4). The sections with the highest rarity values were not as widely dispersed as the other two complementarity analyses, with the top six sections occurring between Albany on the south coast (section 49) and Port Hedland on the north west coast (section 21).

3.4. Comparison of 'hotspots', biogeography and complementarity approaches

The hotspot analyses represented the fewest number of species within the six sections (68.6% of species with species richness, 31.7% with endemism). The species richness hotspots were all located along the north west

Table 3
Complementarity analysis performed on all endemic fishes (Australian and Western Australian, $n = 504$ species) and on just Western Australian endemics ($n = 142$ species), indicating order of section reservation, the total number of species contained in each section, the number of additional endemic species each section brings to the complementarity analysis, and the cumulative number of endemic species represented

All endemics				Western Australian endemics			
Section	Total number of all species	Number of additional endemics	Cumulative number of endemic species	Section	Total number of all species	Number of additional endemics	Cumulative number of endemic species
42	528	286	286	42	528	78	78
27	999	80	366	32	685	22	100
62	339	47	413	27	999	12	112
21	1001	30	443	21	1001	11	123
32	685	12	455	23	1012	3	126
1	823	18	473	49	381	2	128
23	1012	6	479	12	898	3	131
25	973	3	482	45	382	2	133
15	953	2	484	2	820	2	135
49	381	2	486	25	973	1	136
45	382	3	489	26	919	1	137
12	898	3	492	29	713	1	138
2	820	1	493	34	467	1	139
24	1002	1	494	46	369	1	140
26	919	1	495	7	858	1	141
29	713	1	496	55	358	1	142
34	467	1	497				
46	369	1	498				
55	358	3	501				
7	858	1	502				
13	867	1	503				
17	950	1	504				

coast between Port Hedland and North West Cape, while the endemism hotspots were located on the south west coast between Perth and the Recherche Archipelago (Table 1). Both biogeography methods performed better than the hotspot analyses, with a higher percentage of species represented (88.8% centre, 89.5% edge) and the sections selected occurring around the entire coast. The complementarity analysis run using only Western Australian endemics did not perform better than the biogeographic approaches (87.7% of all species). However the complementarity analyses run with all endemics (Australian and Western Australian) and with all species performed better than the biogeographic approaches, representing 95.6% and 95.5% of all species, respectively.

4. Discussion

The patterns of species and endemism richness found in this study concur with earlier work on the distribution of fishes and other taxa along the Western Australian coast (Wilson and Allen, 1987; Morgan and Wells, 1991; Hutchins, 1994, 2001). With increasing latitude the faunal composition changes from a tropical, species rich, Indo-Pacific fauna, to a smaller suite of temperate species, dominated by Australian and Western Australian endemics. The lack of overlap in species richness and endemism hotspots results in low species representation by these two approaches. By selecting the most species rich locations, limited range endemics were not protected, and inversely, conserving endemics resulted in many wide-ranging species being unprotected. This limitation of the hotspot approach has been previously documented in both terrestrial and marine environments (e.g., Pressey and Nicholls, 1989; Reid, 1998; Awad et al., 2002).

The biogeography of Australian marine fauna has been investigated since the 1930s (Whitley, 1932). The majority of these studies have divided the waters off Western Australia into tropical and temperate zones, with a transitional zone along the west coast. While this pattern was also seen in the present study, the primary division occurred on the mid west coast at Shark Bay, at very low levels of similarity, indicating a major difference in the fish fauna of the north and south. There were also some further divisions on the north and west coasts. The division of the north coast at Cape Leveque into a Kimberley region and a Northwest Shelf region was only apparent at a high level of similarity, but confirmed the division noted by Hutchins (2001) for shallow reef fish fauna. The west coast overlap zone was separated into three sections, indicating that it is not a continuous transition, but divided by Shark Bay and the Abrolhos Islands. It is of interest to compare our results to those of the Interim Marine and Coastal Regionalisation of Australia, which was an extensive biogeographic study that divided the waters of Australia into a number of demersal and pelagic regions and biotones, defined using oceanographic climate characteristics and diversity and richness of demersal and pelagic fishes (Australian and New Zealand Environment and Conservation Council, 1998). The demersal and pelagic regionalisations related closely to the results of this study, with the slight differences accounted for by the suites of species considered by the two studies. The present study considered all species that occurred from the coast to the edge of the continental shelf and, unlike the Interim Marine and Coastal Regionalisation study, did not distinguish between pelagic and demersal fishes.

In comparison to the 'hotspot' approach, the sections selected using biogeography were more efficient in terms of representing higher percentages of the Western Australian neritic fish fauna. Many authors have argued that, in order for marine reserves to be representative, it is necessary to have reserves in all biogeographic zones (e.g., Hockey and Branch, 1997; Day and Roff, 2000; Roberts et al., 2003). However, there is debate as to how reserves should be located within biogeographic zones. Reserves placed at the centre of a biogeographic zone will protect representative habitats and biotas, while allowing for the often indistinct boundaries found in the marine environment (Emanuel et al., 1992; Thackway, 1995; Hockey and Branch, 1997). Reserves placed at the edge of biogeographic zones, it is argued, will result in protection of peripheral populations of species, which can provide ecological benefits as these areas tend to have higher species diversity and resilience to environmental variability (Hockey and Branch, 1997; Roberts et al., 2003).

The sections selected by the complementarity analysis on all species occurred around the entire coastline and, as such, represented both tropical and temperate fishes. While the majority of the sections selected occurred north of Perth, the five sections located on the south and southwest coasts were important for representing the Western Australian and Australian endemics that dominate in those regions. The high number of sections selected on the northwest coast was a result of the high species richness in the area, combined with the number of localised records of Indo-Pacific species (e.g., species only recorded on the coral reefs of the Dampier Archipelago or the Montebello Islands, sections 23–25). Since the selection method was based on the summed rarity value of each section (Rebelo and Siegfried, 1992; Turpie et al., 2000), those species with limited distribution ranges within Western Australia were represented because the presence of those species increased the rarity value of the section.

When the complementarity analysis was run on Australian and Western Australian endemic species, the sections selected were the same as the sections selected in the initial complementarity analysis, with only one exception (section 55, Recherche Archipelago). The major difference was the order in which the sections were selected. The same is true for when the complementarity analysis was run on only Western Australian endemics, with only one section being selected that was not in the initial analysis. This similarity in sections was not surprising given that the algorithm used to run the analysis gave higher values to those sections which contained species with limited ranges, which were usually endemic species. When comparing the approaches used, the complementarity analysis run using all endemics (Western Australian and Australian) was slightly more efficient at representing all species than the initial complementarity analysis, in the six sections used. However, this was not the case when all sections selected were examined, as the analysis using all endemics was unable to represent all species.

When compared to the hotspot and biogeographic approaches, the complementarity approaches (except that based on Western Australian endemics only) were more efficient at selecting sections to protect Western Australian neritic fish fauna. Similar results have been found in other studies, both terrestrial (Williams et al., 1996) and marine (Turpie et al., 2000; Awad et al., 2002). Complementarity is closely related to efficiency, as the focus is on minimising the area set aside for reserves (Pressey et al., 1993). The selection of sites based on hotspots of species richness or endemism, or on biogeographic zones did not take into account the complementarity of sites to one another, and was therefore less efficient.

Although the complementarity analysis was the most efficient, there are some limitations that need to be addressed. Firstly, there was a northerly bias in the analysis due to the numbering of the sections (1 in the far north to 62 in the far south). When sections had the same summed rarity values, the most northerly section was selected first. It was expected that this would only impact upon the sections selected towards the end of the analysis, as at the beginning of the analysis there were large differences between the rarity values for sections. Renumbering the sections and repeating the analysis tested this limitation and, as expected, only the latter half of the analysis was affected, where there were only small differences between the rarity values of the sections. The order of selection of some of the sections changed, because when sections had the same summed rarity value, the southerly section was selected first. Although there were four different sections selected, these sections adjoined the sections initially selected. The impact of the northerly bias, therefore, was not significant. In the situation where different sections were selected, this indicated that those sections were interchangeable, and the selection of reserve locations in those areas would be more flexible.

Secondly, although the initial distribution data from the *Zoological Catalogue of Australia* (Hoese et al., in press; Paxton et al., in press) was extensive and covered the majority of the species used, there was some inherent variability. Well-studied species often had distribution ranges that were comprehensive and exact, given to the kilometre or specific locality, while other species were ascribed broad distribution ranges that were open to interpretation. Although species with this form of distribution were treated in a uniform way, this could have resulted in these species (3.1% of the total number of species) being assigned broader or narrower distributions than they actually had. The Western Australian coastline is extensive, with many areas difficult to access, and therefore sample, which has resulted in variability in scientific sampling effort for fishes along the coast. This could have resulted in artificially low species richness in some areas with low sampling intensity, while the situation could be reversed in other areas with high sampling intensity. However, unlike for most other taxa, commercial and recreational fisheries occur around the entire Western Australian coastline and their catches provide additional valuable records on the distribution of fish species. Another limitation of this method was that it was driven by the number and scatter of species with limited distribution ranges. However, as every attempt was made to remove vagrant species from the database, the species with limited distribution ranges were valid species in need of conservation efforts. Many of these species were Western Australian endemics, and if they are not protected in Western Australia, they cannot be protected anywhere else.

Another possible limitation was that the analysis was run at a broad scale (100 km coastal sections, extending from the coast to the 200 m isobath) and, as such, only identified general locations of priority areas for conservation of Western Australian neritic fishes. In this study, the geographic range of the species was interpreted as the extent of occurrence (i.e., the latitudinal limits of a species) and included all the shelf area in this range. Geographic range can also be interpreted as the area of occupancy, which fits within the extent of occurrence but does not include those areas where the species cannot occur due to lack of available habitat (Gaston, 1991; IUCN, 2001). Although the area of occupancy is a more accurate measure of the geographic range of a species, such data were not readily available for Western Australian fishes. It would have been desirable to be able to run the analysis at a level that highlighted the area of occupancy of the fish species, as this would have ensured that specific habitats for the species were represented in the analysis (IUCN, 2001). However, by using 100 km sections extending to the edge of the continental shelf a range of habitat types would be encompassed by each section.

It could be argued that only identifying areas of conservation importance for fishes is a narrow approach. However, previous studies in the Australasian region have shown that the heterogeneous nature of fish distributions can make them relatively effective surrogates for other marine taxa (Ward et al., 1999; Gladstone, 2002; Beger et al., 2003). Patterns of fish species richness and endemism that drove the complementarity analysis have been documented for a range of other taxa, including molluscs (Wilson and Allen, 1987), echinoderms (Marsh and Marshall, 1983) and decapod crustaceans (Morgan and Wells, 1991). It is therefore probable that the areas highlighted for conservation of neritic fishes would coincide with areas of priority for other taxa.

This study stopped at the Western Australian state borders, which are political and not biological borders, and it is possible that the priority areas for conservation identified by the complementarity analysis on the north and south coasts could be mitigated by marine protected areas in other states. Many of the species found on the north coast are broad ranging Indo-Pacific species and, as such, occur across Australia's northern faunal region. As there are no marine protected areas in the Northern Territory, the Great Barrier Reef Marine Park in Queensland is the closest marine protected area to Western Australia's north coast. Of all the fish species that occur in the Western Australian section adjacent to the Northern Territory border (section 1), 54.4% have documented distributions on the Great Barrier Reef. The same situation is true for the south coast. With the recent establishment of the Great Australian Bight Marine Park in South Australia, 96.8% of the fish species occurring in the Western Australia coastal section adjacent to the South Australian border (section 62) could be afforded some protection by this marine park. However, this is only true for Indo-Pacific species and Australian endemics, not Western Australian endemics.

There are currently nine marine protected areas established in Western Australia offering varying levels of protection, ranging from "no take" sanctuary areas, to areas that allow commercial fishing and oil exploration. These marine protected areas are concentrated on the west and north west coasts of the state (Fig. 1), and at the time of this study, there were no marine biodiversity conservation areas on the north or south coasts. The marine protected areas in the north west will provide some protection to this species rich location, but protection for Western Australian and Australian endemics is scant. Although there are three marine protected areas in the Perth metropolitan area, which has the highest number of endemic fish species in the state, these marine protected areas are very small (total area 16,392 ha) with the area of "no take" being even smaller (434 ha) (Department of Conservation and Land Management, pers. commun.). In light of the results from this study, it is clear that future marine conservation efforts in Western Australia need to focus on the north and south coasts of the state.

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