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Summary of the stock structure information used for determining spatial management of the index species for the scalefish resources of northern Western Australia

Daniel J. Gaughan
daniel.gaughan@dpird.wa.gov.au

Stephen J. Newman
Stephen.Newman@dpird.wa.gov.au

Corey B. Wakefield

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Gaughan, D.J., Newman, S.J., and Wakefield, C.B.

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Department of Primary Industries and Regional Development
Gordon Stephenson House
140 William Street
PERTH WA 6000
Telephone: (08) 6551 4444
Website: dpird.wa.gov.au
ABN: 18 951 343 745

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Acronyms & Abbreviations

CPUE	Catch per unit effort
F	Fishing mortality
FAO	Food and Agriculture Organisation
MSC	Marine Stewardship Council
mtDNA	Mitochondrial DNA
NWS	North West Shelf
P1	Principle 1
PTMF	Pilbara Trap Managed Fishery
SSB	Spawning Stock Biomass
UoA	Unit of Assessment
UoA	Unit of Certification
WA	Western Australia

1 Purpose

This paper summarises the basis for how the Government of Western Australia (WA) determines the most appropriate spatial scales to undertake the management, monitoring and assessment of marine fish stocks (i.e. “spatial management”) along the northern coast of Western Australia.

This paper was specifically developed in response to issues raised in an assessment of the Pilbara Trap Managed Fishery (PTMF) against the fishery sustainability standard of the Marine Stewardship Council (MSC). It is intended that the technical aspects of this document will be peer-reviewed within the international scientific literature. This standalone version of the document will also be made available to all stakeholders as a normal part of the MSC certification process.

2 Background to spatial management in Western Australia

The key principles of spatial management are introduced here to set the context for this paper; these key principles will be returned to throughout this paper.

Consideration of the stock structure for exploited populations is a fundamental resource management issue. This issue does, however, have a number of facets and therefore the term stock is often used interchangeably to cover a variety of meanings including species, population, breeding stock, and management unit. For fisheries management, determining the most appropriate and practical boundaries for the measurement of spawning/breeding stock status is clearly the most important 'stock structure' to define. This is entirely consistent with some definitions provided later. Fundamentally, fisheries management is based on the Stock-Recruitment relationship and hence the status of the entire 'source' stock needs to be assessed to determine the likely impacts on future recruitment.

Within the area of a breeding stock, smaller spatial units may be defined as part of overall stock management purposes to avoid local depletion. The methods to determine if such additional spatial units are needed to manage catch levels include adult and juvenile movement studies, assessment of spatial differentiation in population parameters and otolith chemistry studies. It is important to note that some of these latter studies can only assess relative levels of mixing between areas and "they do not imply that such groups of fish constitute separate breeding populations" (Edmonds & Fletcher, 1997). It is acknowledged that some of the text in later studies on stock structure in Western Australia may not have been as clear on this point (see below).

Although otolith chemistry and tagging studies provide information on movements and spatial mixing of many demersal scalefish along the WA coast and have suggested limited adult movement in several cases, the evidence from genetics of these species and the spawning characteristics and oceanographic conditions in this area generally provide evidence of low genetic heterogeneity across relatively large spatial scales. These are the types of factors that were not always considered in some of the earlier studies of otolith chemistry in WA, leading to a need to reassess those works (Gaughan, in prep). Mixing over large scales is highly likely to be achieved through the extensive dispersal of pelagic eggs and larvae. The likelihood that a high proportion of the recruits that settle within a relatively small subsection of this coastline will be distinct from adjacent sections of coast and self-sourced from within these same small areas is remote. While finer and finer scales of spatial division could be invoked, these are traded off against the practicability of assessment and management intervention. Therefore, these broader, regional levels of division are the scale at which the status of the breeding stocks are assessed.

Smaller scale management units have been established where required within each of these broader breeding stock regions to ensure that fishing operations are conducted in a manner that is cognisant of a degree of spatial structure of adult fish. This hierarchical management approach is based on the understanding that there is relatively limited mixing of adults among distant areas and uncertainty in mixing rates between closer locations.

3 Key issues to be addressed

As stated above, the term “stock” has been used in various ways; the spatial management of fisheries in WA is consistent with the MSC definition of “stock”: *The living resources in the community or population from which catches are taken in a fishery. Use of the term stock implies that the particular population is a biologically distinct unit. As noted in the FAO Fisheries Glossary, some species form a single stock (e.g. southern bluefin tuna) while others are composed of several stocks (e.g. albacore tuna in the Pacific Ocean comprises separate Northern and Southern stocks).* However, agreement with this high level definition has not precluded different operational interpretations of stock structure. This may be partly due to the inherent difficulty of stock structure science leading to divergent views on whether stock boundaries exists and if so where they are located, what levels of mixing between areas are significant for management, influence of habitat availability and productivity etc. This appears to be the basis of the issue identified in the MSC certification assessment.

Based on the information about the fishery and the MSC requirements concerning stock complexes, the Assessment Team considers that rather than treating each index species as a single stock unit within the Pilbara, the status of the index species should be examined on an area-by-area basis (Area 0, West and East). Therefore, instead of evaluating only 3 stocks (the 3 Index species) in PI 1.1.1 and PI 1.1.2, a total of 9 elements have been evaluated (3 Index species in 3 areas). The basis for the three stocks conclusion is summarised from the draft client report as follows:

> *For red emperor, Stephenson et al. (2001) noted differences in the stable isotopes between different areas of the Pilbara and concluded that within the Pilbara area there was limited red emperor movement on a scale of 130 nautical miles. Although there may have been some movement of red emperor between the open and closed areas, there did not appear to be extensive longshore movement. While their study did not exclude the possibility of extensive mixing of Rankin cod within the Pilbara, it did appear that east and west Pilbara fish were not fully mixing. For bluespotted emperor the assessment document specifically states "elemental analysis of sagittal otolith chemistry indicated that populations were separate on fine spatial scales, i.e. limited adult movement (Moran et al. 1993)."*
>
> *In addition to the evidence for stock separation within the Pilbara provided by otolith chemistry and by management responses to concerns about local stock depletion, the outputs from the stock assessment also indicate that it is inappropriate to regard the scalefish in the Pilbara region as a single stock. Trends in area-by area information from the integrated model (Appendix 5 of the assessment document) indicate differences between areas (“0”, “West” and “East”) for SSB, F and recruitment for both red emperor and bluespotted emperor. For Rankin cod (Appendix 8), the results for the different areas are more similar, but there are still differences, especially between Area 0 and the West and East areas.*

4 Key relevant aspects of the MSC Standard

Stock complexes are considered from a scoring perspective in the MSC Certification Requirements 2.0 (SA2.2.5, SA2.2.6). The requirements include:

The certification guidance volume provides information on defining Units of Certification / Units of Assessment (UoCs/UoAs), including consideration of multi-stocks, mixed stocks, and meta-populations (GSA2, p. 143; G7.47 – G7.4.9). The guidance includes:

> *The UoC is defined as follows: The target stock or stocks (=biologically distinct unit/s) combined with the fishing method/gear and practise etc*
>
> *In the context of defining a UoC/UoA, stocks could be different species, or different 'more or less isolated and self-sustaining' groups within a species. UoCs/UoAs are usually defined for single species (or stocks) and gear types.*

This paper will outline why the Government of WA considers that each of the three index species in the Pilbara are not biologically distinct units so should not be considered as separate UoCs. The information presented attempts to update and/or clarify on that provided previously and thereby reconcile the different scientific opinions regarding stock structure of the three index species, noting the possibility that while both views are not consistent each may be equally valid. A key theme of this report is uncertainty around level of spatial mixing through the geographical distribution of each index species. The overriding aim of the report is to provide sufficient information to permit the guidance provided in Table G2 (p. 25, see Appendix A.) to be the basis for determining what degree of connectivity and self-recruitment most likely applies for the index species in question.

5 Review of the WA approach

An initial review of contemporary knowledge on this topic indicates that the management approach taken in WA is not only appropriately precautionary but is also consistent with the approaches used elsewhere in the world (Cadrin et al. 2014; Secor 2014; Kritzer and Liu, 2014). In the first edition of *Stock Identification Methods* Cadrin et al. (2007) noted that despite the long history of stock identification and the many methodological advancements the definition of management units remains a practical decision because it depends on the management objective. This has subsequently remained a consistent message: in WA we therefore agree with the more recent view in the 2nd edition of *Stock Identification Methods* that management units should be practical reflections of biological population structure (Cadrin et al. 2014).

6 Stock assessment considerations

In their consideration of assessment implications of complex spatial structure Kritzer and Liu (2014) note that data deficiencies have most likely played an important role in limiting the use of assessments that account for distinct demographic units. Thus, while population assessments should attempt to consider population structure, logistical constrains necessitate models of less complexity than would be ideal. Similarly, Kritzer and Liu (2014) note that even if spatial structure is considered within a model that does not necessarily mean that the resulting management advice will be spatially explicit.

7 Western Australian perspective

7.1 Spatial management

There are very few marine fish in Australian coastal (shelf) waters that undertake cohesive, predictable migrations and likewise relatively few that are considered to constitute a single management unit throughout their range. In southwestern Australia, largescale alongshore, spawning migrations occur only for Australian herring, *Arripis georgianus,* and Australian salmon, *Arripis truttaceus*; southern bluefin tuna, *Thunnus maccoyii*, migrate south and then west along the continental shelf as part of a global migration; and some shark species exhibit predictable size-related movements covering 1000s km (Gaughan, in prep.). Such cohesive migrations have been a major factor in determining that fish form single stocks. For many other exploited Australian marine fish there is insufficient information to demarcate cohesive stocks, with many species spread more or less continuously throughout their range, but with regionally variable abundance and population parameters. These may or may not exhibit movements in local areas (i.e. cross-shelf movements), alongshore (e.g. age/size/spawning/ seasonal related movements) or annual spawning aggregations.

As acknowledged above, the spatial scale of fisheries management needs to be matched with the spatial scale of biologically relevant processes for the resource. However, although a stock assessment must consider this overall spatial scale, the management arrangements can include elements that operate at smaller scales. This could be for a number of reasons including constraints on the operational scale of monitoring and compliance, patterns of fishing operations and management objectives (e.g. reducing the risk of local depletion, distributing fishing effort etc.). There are many examples of fisheries for which a single biological stock is subjected to a level of spatial management. Thus, many coastal marine fish have been classified as single genetic stocks through their entire distributions but the geographic scale of the single-stock approach is often greater than can be effectively managed due to, for example, spatially variable abundance and patterns of exploitation combined with poor knowledge of the spatial dynamics within a species range. This acknowledgement is consistent with the conclusion by Kritzer and Liu (2014) that spatial management arrangements in some cases are likely to be the result of historical development of a fishery, politics and policy, scientific advancements, and inertia. In recognition of the potential risks to a population posed by inadequate spatial management there have been many studies on “stock structure” of marine fish in Australia.

7.2 Stock structure studies

Several methods have been used to assess stock structure and or movement patterns of marine fish in WA and Australia more broadly including tagging (various), genetics (various), otolith chemistry (various), morphometrics and meristics, life history characteristics and population biology — all approaches that have been used globally (Cadrin et al., 2014). Of these, the primary method that has provided evidence that spatial management is warranted for marine scalefish in WA has been examination of otolith chemical composition, i.e. heavy metal concentrations and/or ratios of carbon and oxygen stable isotopes (Gaughan in prep).

Consequently, this summary will focus on the application and interpretation of otolith chemistry studies as relevant to the index species for the scalefish resources in the Pilbara region. Application of these cost-effective methods burgeoned in the 1990s (e.g. Kalish 1991; Edmonds and Fletcher 1997; Campana 1999; Campana & Thorrold 2001). Because the stable isotope ratio for oxygen is related to temperature this chemical signal has been particularly useful in WA due to the cline in temperature from the northern tropics to southern warm-temperate regions.

7.3 Otolith chemistry studies

Otolith chemistry methods have been applied to several species in WA, including the index species for the north coast scalefish fisheries (see below), to help elucidate if there were separate stocks or at least demonstrate that mixing was sufficiently limited over a species' distribution to warrant consideration of separate management units. The studies on marine species sampled along temperature clines invariably found differences in stable isotope ratios for oxygen and concluded these indicated isolated or non-mixing groups of fish that could be considered as separate stocks (e.g. Stephenson et al. 2001). Similarly, studies of otolith elemental composition typically found differences if the samples were from widely separate locations (e.g. Moran et al. 1993).

However, improvements in understanding of the application and analysis of otolith chemical signatures over the past 20 years (e.g. Kerr and Campana, 2014; Stanley et al. 2016) suggest that the interpretation of results from earlier studies in WA can now be considered outdated (Gaughan, in prep.). In particular, comparison of average oxygen stable isotope ratio samples from widely separated locations along a temperature cline provide no quantitative information on mixing rates within the distribution of a species. The same applies to comparing mean elemental signals (or multivariate derivations of these) across widely separated locations. Consequently, while such studies do indicate a lack of panmixia over an average lifespan of the sampled species they cannot provide definitive advice on the presence of stock structure. The reasons for this conclusion are explored further below.

Stanley et al. (2016) recognizes the challenge posed by continuous distributions of individuals and spatial–temporal variability in environment to the assignment of coastal marine fishes to particular locations on small scales. This same challenge is fully relevant to otolith chemistry studies in Western Australia despite the different spatial scale. Thus, the challenge for attempting to discriminate stocks of marine species in WA is that sampling relatively few locations are over large distances fails to sample on a sufficiently fine/intensive scale to obtain adequate information on mixing. Rather, conclusions on mixing have been dictated by the sampling design and can now be seen to be no longer valid in some cases, particularly if no other information was available or considered when interpreting the chemical signatures. Abaunza et al. (2014) have expressed concern at the lack of emphasis on sampling design in stock structure studies and further noted that sample design is a crucial aspect of stock identification studies. In a study on northern cod nursery habitats in Newfoundland Stanley et al. (2016) demonstrated a declining assignment success with an increased number of sample sites. That is, the more sites sampled translates to a lower ability to detect difference; this would particularly be the case if sampling occurred along a cline of factors that directly influenced the chemical signature of the otoliths.

Stephenson et al. (2001), who studied otolith chemistry of red emperor and Rankin cod (see below) based their conclusions on 14 locations spaced across 1850 km whereas Stanley et al. (2016) had data from 17 locations across only 800 km of coastline in Newfoundland. The Newfoundland study observed improved classification-assignment success at increasing spatial scale and it is highly likely that the same would have been found in NW Australia for both red emperor and Rankin cod if the intensity of sampling had been higher. That is, samples closer together are more difficult to distinguish. Stephenson et al. focused their analysis on determining if location means differed rather than using the more sophisticated assignment analysis available now; nonetheless, even though the approach of Stephenson et al. found that nearer locations were more similar than distance locations they did not provide any information on mixing rates so cannot make conclusions regarding distinctness, a prerequisite for identifying separate stocks. Hence, the typical experimental design and analysis used in WA cannot discriminate stocks or management units at relatively fine spatial scales, and certainly not in isolation of other information. Stanley et al. (2016) concluded that accurate assignment of individuals, populations, or locations normally requires sampling all possible geographic sources in a region because failure to do so may result in major errors during mixture analysis or assignment. Sampling all geographic locations has not been the case in most WA studies using otolith chemistry; it remains to be seen whether retrospective assignment analyses might provide estimates of, or insight into, mixing rates for some of the marine index species in WA for which otolith chemistry methods have been applied. The now recognised inability of these studies to determine stock structure based solely on examination of average isotopic ratios from distant sampling locations appears to be unequivocal.

This initial critical examination of some older otolith chemistry studies against a more recent example is provided here to underpin the caution required for interpreting the otolith chemistry signals for the northern WA scalefish index species.

8 Stock structure summary of Pilbara index species

8.1 Application of national definitions and lines of evidence

Within the *Status of key Australian fish stocks reports*[1] the term 'stock' is used interchangeably in reference to three levels of stock status assessment - biological stocks, management units and populations assessed at the jurisdictional level.

A biological stock is defined as – a genetically or functionally discrete population that is largely distinct from other populations of the same species and can be regarded as a separate homogeneous group for management or assessment purposes (see *Status of key Australian fish stocks reports* Glossary[2]). Where assessments cannot be completed at the biological stock level, they are undertaken and used for management at the management unit level (e.g. Orange roughy[3]; pink snapper[4]; yellow-eye mullet[5]. This approach is consistent with the definition provided in Cadrin et al. (2014):

> *Stock - An exploited fishery unit. A stock may be a single spawning component, a biological population, a metapopulation, or comprise portions of these units. For management purposes stocks are considered discrete units, and each stock can be exploited independently or catches can be assigned to the stock of origin.*

Different techniques or methods for assessing spatial dynamics provide different types of information and at different time scales that can contribute to identifying stock structure. In terms of genetic techniques, the population genetics approach can test hypotheses of present day or past patterns of dispersal (mixing) while population kinship approaches examine relatedness among individuals within and across generations. Population genetic divergence is commonly regarded as being inversely proportional to present-day rates of bilateral mixing (i.e. low genetic divergence suggests high mixing). If there are physical barriers to mixing, or strong evidence that mixing is not occurring, population genetic divergence reflects historical separation between populations. Otolith chemical signatures, parasites and population parameters can provide information about the level of mixing which, in turn, depending on the specific details of the information available, can also provide information of the likelihood of the presence of discrete adult assemblages.

In addition, the potential for relative levels of mixing within a population (or across the range of a species) can also be inferred from a species' life history strategy. The two primary modes of dispersal typically exhibited by marine teleosts are; 1) passive dispersal of pelagic/planktonic eggs and larvae and/or 2) swimming by larval, juvenile or adult fish. The level of mixing from egg and larval dispersal is influenced by the spatial-temporal patterns of spawning relative to the prevailing oceanographic currents, the duration of the spawning

[1] http://www.fish.gov.au/Reports
[2] http://www.fish.gov.au/Overview/Glossary
[3] http://www.fish.gov.au/report/44-Orange-Roughy-2016
[4] http://www.fish.gov.au/report/60-Snapper-2016
[5] http://www.fish.gov.au/report/79-Yelloweye-Mullet-2016

period and the periodicity of spawning (i.e. determinate or indeterminate spawning strategies). For example, a species with indeterminate spawning of pelagic eggs, with spawning occurring over a large portion of the continental shelf for a protracted period (i.e. 10-12 months a year) would very likely have a higher level of egg and larval dispersal (and much wider spatial stock extent, within other constraints such as habitat preference) than a species that forms spawning aggregations in a few marine embayments for only a few months each year.

The following sections summarise information for each of the three index species of concern in the Pilbara region.

8.2 Red emperor *(Lutjanus sebae)* stock structure

van Herwerden et al. (2009) examined the genetic connectivity of *L. sebae* using mtDNA from samples collected in the vicinity of Browse Island in the Kimberley and at the Montebello Islands, in the Pilbara (Figure 1). The WA sites were compared to sites on the east coast of Australia, which demonstrated that eastern and western Australian populations of *L. sebae* form a single inter-breeding genetic stock (van Herwerden et al. 2009). As alongshore movements of a significant proportion of the adult *L. sebae* are apparently limited (Stephenson et al. 2001), the observed high level of gene flow indicates that there is sufficient dispersal of *L. sebae* eggs and larvae around the Australian coastline to maintain high gene flow, possibly augmented by some level of juvenile and adult dispersal.

The results of van Herwerden et al. (2009) confirm those derived by Johnson et al. (1993) using allozymes for *L. sebae* in Western Australian waters. Johnson et al. (1993) examined samples of *L. sebae* from the Lacepede Islands, Bedout island, Lowendal Islands, Ningaloo and Shark Bay (Figure 1). The level of variation of the *L. sebae* samples were the lowest of all the species examined by Johnson et al. (1993). The average Fst was very low (0.003), with Johnson et al. (1993) reporting a high degree of connection among populations throughout the sampled range of 2,100 km in Western Australia.

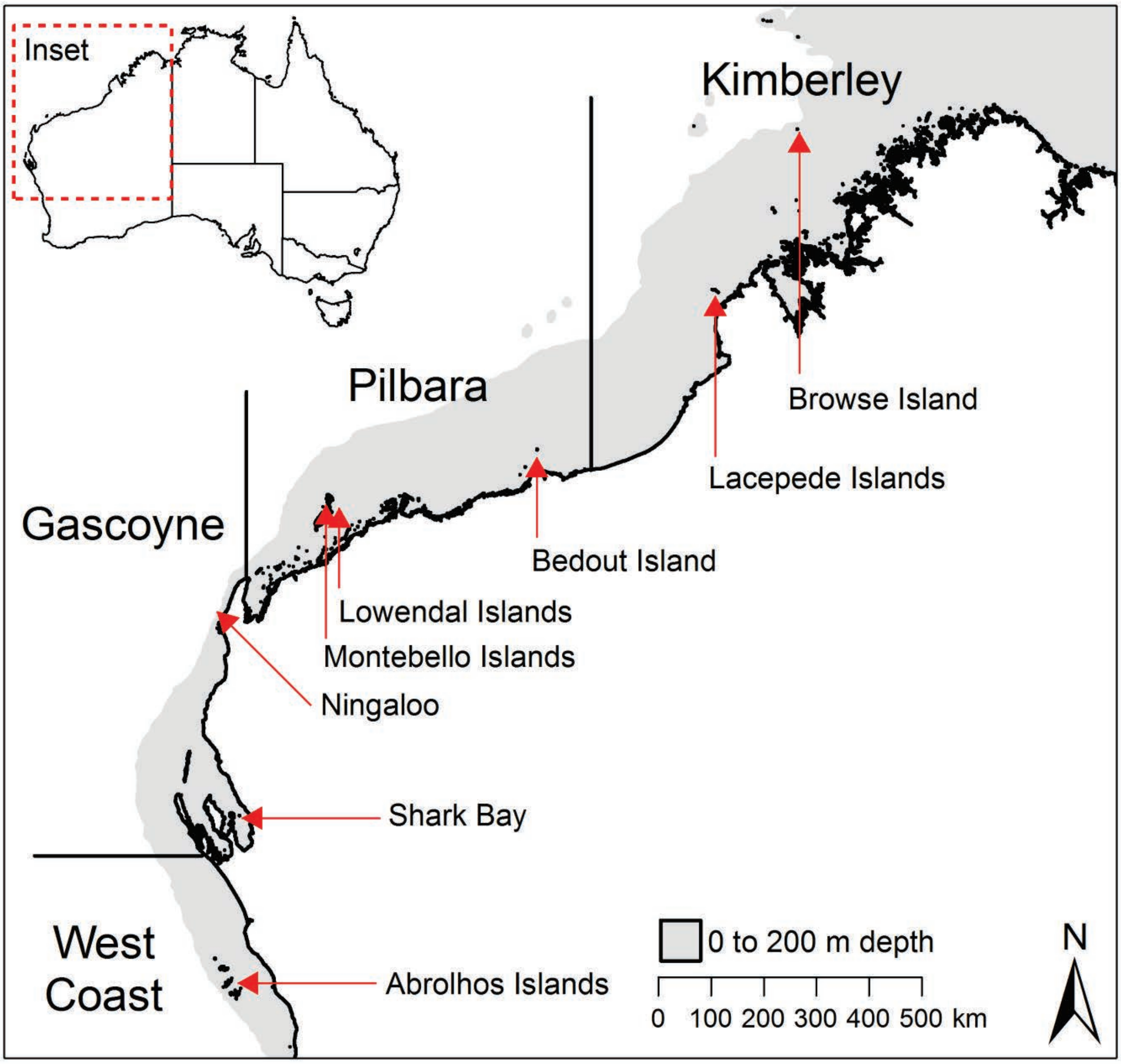

Figure 1 Map showing sampling locations for stock structure studies within the Kimberley, Pilbara, Gascoyne and West Coast regions of north-western Australia.

Stephenson et al. (2001) examined stable isotopes in sagittal otolith carbonates of *L. sebae* from four regional locations; Shark Bay (Gascoyne), Ningaloo (Gascoyne), Pilbara and Broome (Kimberley; Figure 1). Significant differences in stable isotope ratios provided evidence that there was limited mixing of adult *L. sebae* between three broad zones; Shark Bay (Gascoyne), Pilbara, and Broome, a distance of approximately 1,600 km. Therefore, these broad locations could be managed separately for the purposes of fishery management.

While the experimental and analytical design for isotopic ration studies of Stephenson et al. (2001) could not quantify mixing rates (see above, Gaughan, in prep), the data were sufficient to indicate a more likely degree of partial mixing of *L. sebae* from Pilbara west and east sites than between more distance sites. The overlap in the otolith stable isotope signatures between some sites potentially reflects mixing by a proportion of juvenile or adult fish, not just eggs and larvae; or that they are continuously distributed along an environmental cline but mix sufficiently to have been captured at the particular separate locations (Gaughan, in prep.).

The reproductive biology of *L. sebae* results in a very broad distribution of eggs and larvae, which assists in explaining the genetic connectivity over a wide geographic range. This species is an indeterminate spawner (evident from gonadal histology) that releases pelagic eggs. It is continuously distributed across the entire continental shelf (in depths of 30-120 m) during the whole year and spawns for 10-12 months of the year on the north coast of Western Australia (Figure 2, Figure 3). Thus, this species exhibits a strong broadcast spawning strategy with egg and larval dispersal subject to annual variations in oceanographic currents along the north coast of Western Australia. The entire North West Shelf (NWS) of WA experiences considerable alongshore currents, flowing mainly northeast over summer and southwest over winter (Condie and Adrewartha, 2008). Particle tracking models (e.g. see Figure 4) demonstrate that there would be considerable bidirectional mixing of pelagic eggs and larvae in both directions along the NWS for species with spawning seasons that extend through both the winter and summer seasons.

8.2.1 Summary

Genetic analysis has demonstrated that Kimberley (eastern) and Pilbara (western Australian) *L. sebae* form a single inter-breeding genetic stock (van Herwerden et al. 2009); there is no evidence of discrete breeding populations of *L. sebae* in WA.

While, otolith stable isotope chemistry suggests limited mixing of juveniles and adults between widely separated locations this method cannot determine the extent of mixing at smaller scales. Thus, the decision to manage *L. sebae* as two regional management units (Pilbara and Kimberley) is a precautionary approach that acknowledges this limited mixing across large distances and uncertainty in mixing rates across smaller distances. Noting the *L. sebae* occurs along 2000 km of coastline, the large distances involved and uncertainty over the mixing rates of juveniles and adults, stock assessments conducted on a regional scale (e.g. Pilbara and Kimberley) provide a more conservative approach to managing the resource.

Therefore, *L. sebae* assemblages in the Kimberley and Pilbara are considered as separate management units but are not genetically discrete populations.

The location of the boundary for the two management units, which determines the break in spatial extent of the two stock assessments, is an artificial construct which reflects both a practical spatial division of the single genetic stock and the historical development of the fisheries in the Pilbara and Kimberley regions. This is consistent with the modern concept of a stock identification (Secor, 2014).

Although there is likely to be widespread mixing of eggs and larvae, adult movements are likely to be less but nonetheless some proportion of juveniles and adults are likely to mix across relatively long distances. The differences in SSB and F are consistent with this scenario (and effects of different levels of localised depletion). With respect to recruitment,

1) the trends in deviations about the stock-recruitment curve are similar among areas, consistent with that expected if recruits were derived from one source (or alternatively, that environmental conditions affecting egg/larval survival are very similar everywhere).

2) If there are differences in estimated recruitment levels among areas, this will, at least in part, reflect the modelling assumptions made for the assessment – i.e. in particular, the use of a separate stock-recruitment curve for each area – which would mean that if adult biomass had declined in one area, this would directly impact the model estimate of the recruitment level for that area. Alternatively, an assessment model could have been constructed assuming a single stock-recruitment curve for the overall area (for the single stock), each year distributing (an estimated) proportion of early recruits to each area. This would have meant that the recruitment to each area was linked to overall stock abundance (i.e. across all areas). In other words, the assessment results (as will always be the case), are dependent on the modelling assumptions made. Thus, the noted differences do not necessarily reflect that there are "several stocks" with Figure 3 showing a continuous distribution of this species throughout the Pilbara region. For non-panmictic stocks a degree of spatial variability in population parameters, abundance and recruitment levels look to be the normal situation in WA waters rather than the exception.

Assessing stock status of *L. sebae* in WA at the level of the fishery management units (e.g. Kimberley, Pilbara) has been accepted in the *Status of key Australian fish stocks reports* (e.g. Newman et al. 2016). In some cases a further level of spatial management has been implemented, such as a series of zones within a fishery e.g. Pilbara Fish Trawl (Interim) Managed Fishery. These spatial units are designed to distribute effort over the extent of the fishery to minimise the risk of localised depletion. Reiterating from above, all the spatial units contribute to the adult spawning stock within WA (i.e. the spawning stock is comprised of the total of all the spatial units). *Within the WA jurisdiction the smaller spatial scales may be examined during the assessment process to better understand the fishery and implement more effective management measures.*

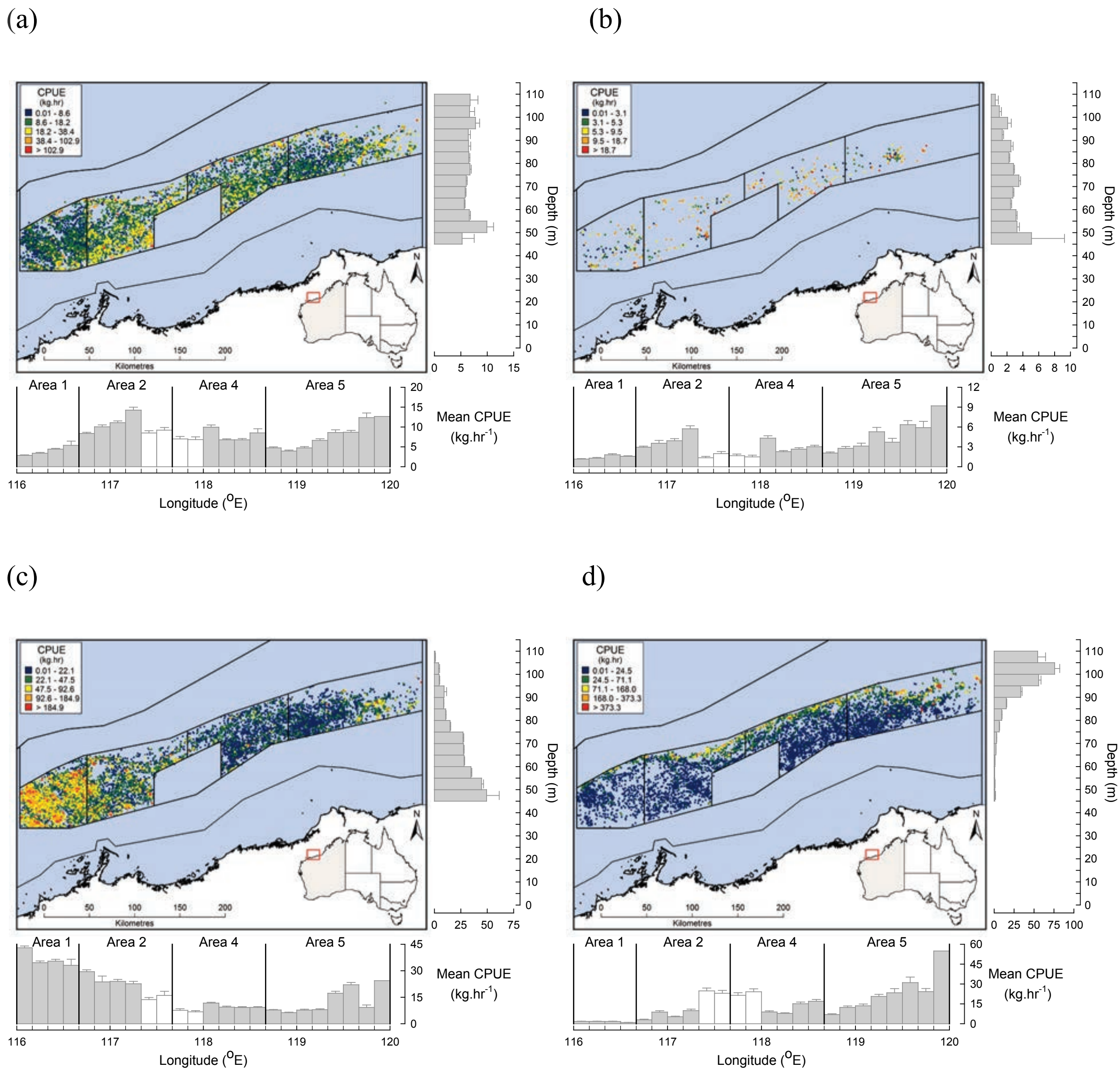

Figure 2. Spatial distribution of catch per unit effort (CPUE) for the mid-point of each trawl from 2004-2008 for four indicator species, including (a) *Lutjanus sebae*, (b) *Epinephelus multinotatus* and (c) *Lethrinus punctulatus* [and (d) *Pristipomoides multidens*]. The mean CPUE is shown for each 10’ of latitude (below, white bars represent latitudes incorporating closed Area 3) and sequential 5 m depths (right) for each species.

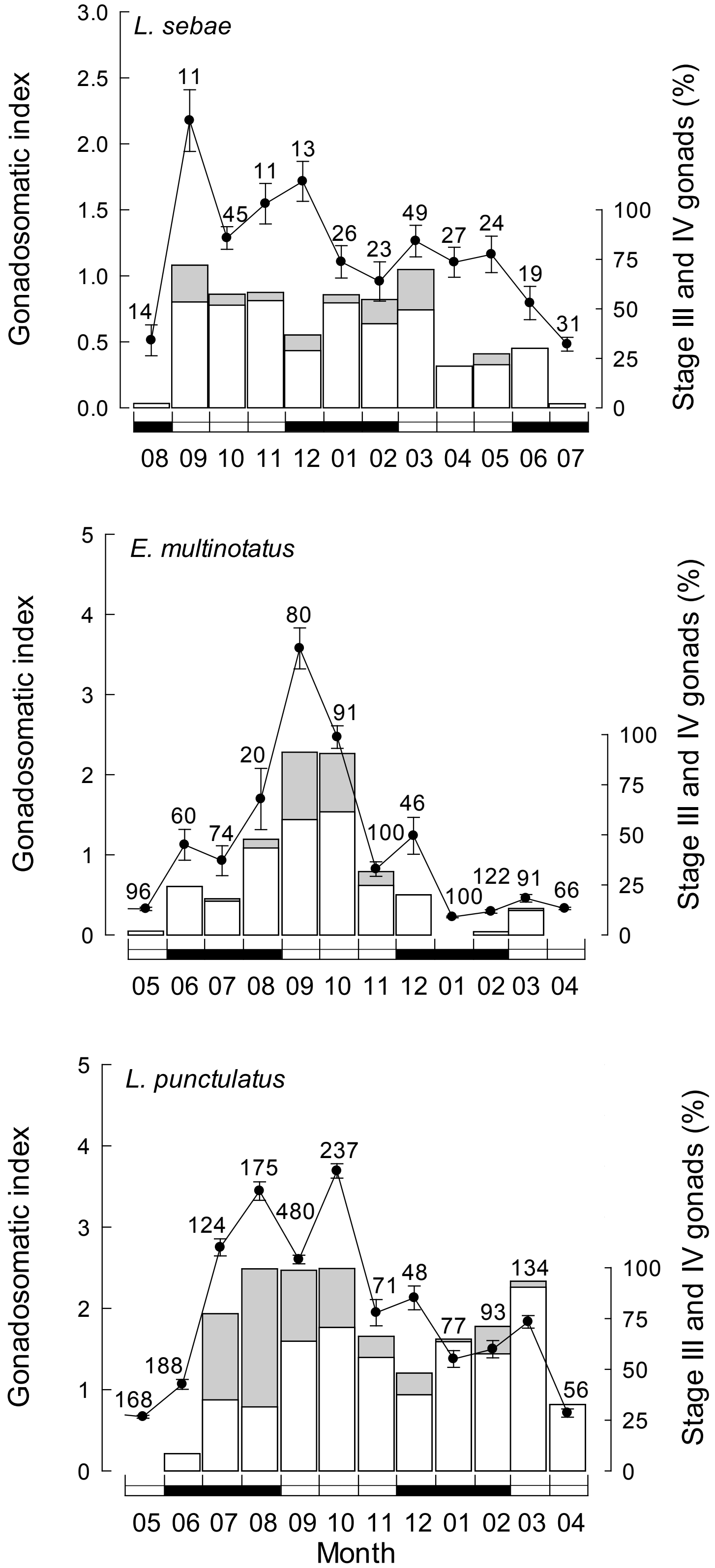

Figure 3. Mean monthly gonadosomatic indices of females (±1 SE) and percentage of females with developed (stage III, white bars) or ripe (stage IV, grey bars) ovaries for fish ≥ L50 at maturity (sample sizes shown) for *Lutjanus sebae* (above), *Epinephelus multinotatus* (middle) and *Lethrinus punctulatus* (bottom). On the x-axis, the closed rectangles represent winter and summer months and the open rectangles autumn and spring months.

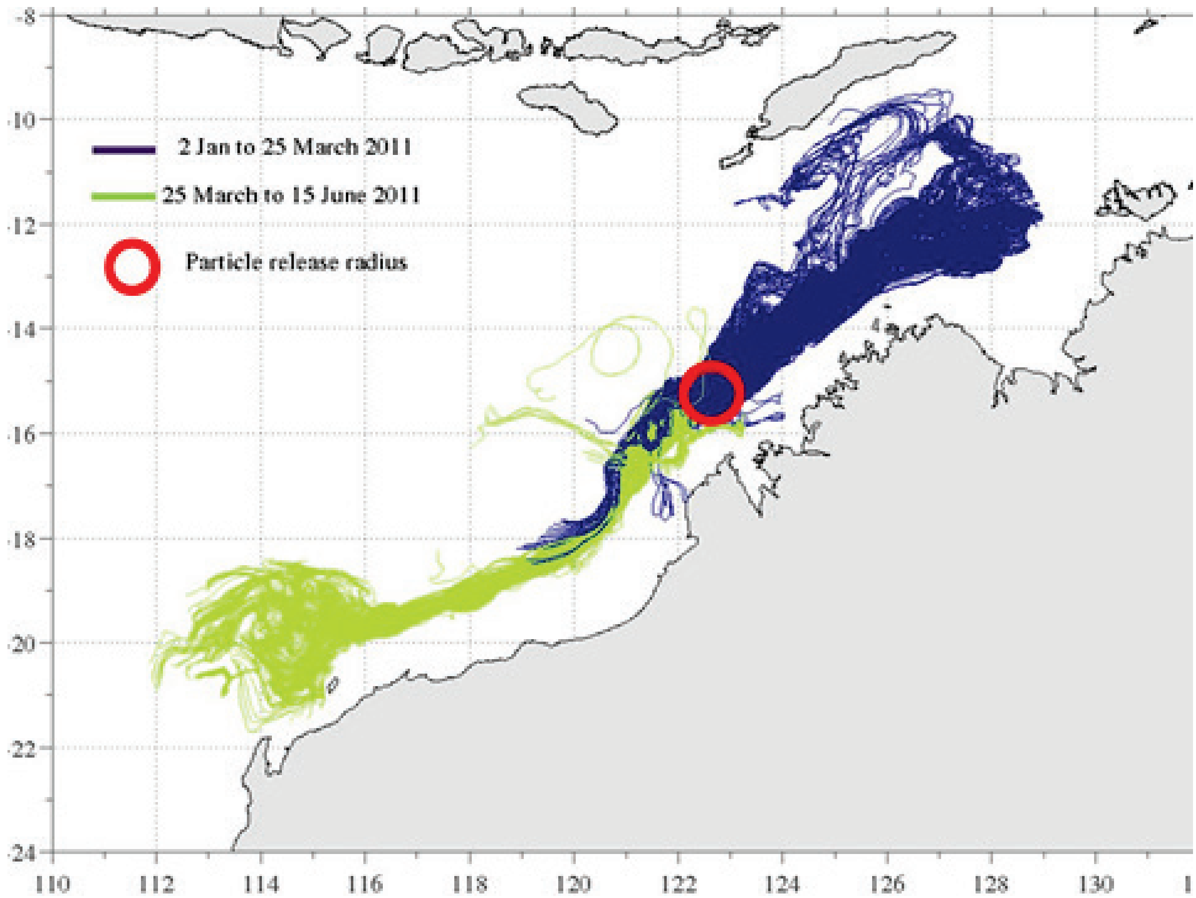

Figure 4. Summer and winter particle drift patterns. This figure show particle tracks for two periods of about 2.5 months; while longer than drift periods expected of pelagic eggs and larvae for the P1 species (e.g. days to weeks, not months), the patterns nonetheless indicate that for continuously distributed species spawning over their range throughout northern Western Australian marine waters there is a high propensity for alongshore mixing (Source: Pattiaratchi et al. 2014)

8.3 Rankin cod (*Epinephelus multinotatus*) stock structure

Johnson et al. (1993) examined allozymes from samples of *E. multinotatus* from the Lacepede Islands, Bedout Island, Lowendal Islands, Ningaloo and Shark Bay (Figure 1). The average Fst was low (0.012), with most variation due to one locus. Johnson et al. (1993) reported a latitudinal cline in the frequency of one allele. These results indicated that the adult population was not totally intermixed. However, the low level of genetic variation indicates extensive connectivity among populations over large distances (at least 1,400 km). It was noted that no adjacent samples differed significantly, indicating the continuity of the clinal change. Regardless of the clinal change evident in just one of 6 loci, genetic connectivity was extensive. Therefore, there is a high degree of connection among populations throughout the sampled range in WA.

Stephenson et al. (2001) examined stable isotopes in sagittal otolith carbonates of *E. multinotatus* from four locations; Shark Bay (Gascoyne), Ningaloo (Gascoyne), Pilbara, and Broome (Kimberley; Figure 1). For *E. multinotatus*, the stable isotope signatures indicated more extensive mixing between the Pilbara and Tantabiddi (the Ningaloo site), and within the Pilbara, than for *L. sebae*. The results of Stephenson et al. (2001) indicated that *E. multinotatus* adults exhibit a higher degree of mixing than *L. sebae* throughout the sampled range.

The reproductive biology of *E. multinotatus* exhibits a very similar broadcast spawning strategy to *L. sebae*; they are indeterminate spawners of pelagic eggs over a protracted spawning period (8-10 months of the year) and appear to spawn across much of the continental shelf of the Pilbara region as evidenced from the spatial distribution of commercial catches of *E. multinotatus* during the spawning period (Figure 2 and Figure 3). This reproductive strategy facilitates broad dispersal of the pelagic eggs and larvae by alongshore currents (Figure 4) and provides a model that is consistent with extensive genetic connectivity across the species' large geographic range.

8.3.1 Summary

Many of the same arguments put forward for *L. sebae* also apply to *E. multinotatus.*

There is no evidence of discrete breeding populations of *E. multinotatus* in WA. Although adults do not mix extensively, they all contribute to the total adult spawning stock. The limited mixing among locations at the broad scale supports the use of regional fishery management boundaries in WA e.g. Pilbara and Kimberley. Given the large distances involved and uncertainty over actual mixing rates of juveniles and adults, the regionally separate stock assessments provide a more conservative approach to managing this resource that is spread across the Kimberley and Pilbara regions. As with *L. sebae* the stock status of *E. multinotatus* in WA is thus assessed at the level of each of the fishery management units in Western Australia despite it being a single genetic stock (i.e. Kimberley, Pilbara).

8.4 Blue spotted emperor *(Lethrinus punctulatus)* stock structure

Johnson et al. (1993) examined allozymes from samples of *L. punctulatus* from the following WA locations; Lacepede Islands, Bedout Island, Lowendal Islands, Ningaloo, Shark Bay and Abrolhos Islands (spread over a distance of approx. 2,000 km; Figure 1). The species showed little geographic variation (average Fst 0.06). While adult populations were not totally intermixed, the low level of genetic variation indicates extensive connectivity among populations over large distances. Moran et al. (1993) examined the elemental composition (Ba, Cd, Cu, K, Mg, Na, Pb, S, Sr, Zn) of *L. punctulatus* otoliths from three locations; Bedout Island (Pilbara), Point Maud (Ningaloo, Gascoyne) and Alison Point (Ningaloo, Gascoyne), spread over a distance of 800 km (Figure 1). Although significant differences were apparently evident between all three locations sampled, only one location was in the Pilbara region. Furthermore, doubt over the efficacy of the analysis of the elemental data by Moran at al. (Gaughan, in prep) and the continuous distribution of *L. punctulatus* shown by commercial catch data (see below) suggest that there is only a single stock in the Pilbara region.

Lethrinus punctulatus exhibits a life history strategy that results in a very high population production, and as such this species consistently supports the highest catches of any species within the Pilbara demersal scalefish resource. The reproductive biology of this species consists of: age at 50% maturity at ~18 months, indeterminate spawning releasing pelagic eggs over a protracted spawning period (11 months of the year) in locations dispersed along the entire continental shelf throughout their distribution (Figure 2 and Figure 3). There is no evidence of discrete spawning populations within the continuous distribution of this species throughout the Pilbara region. Particle dispersal modelling indicates there would be considerable alongshore movement of the pelagic egg and larval stages (Figure 4).

8.4.1 Summary

Many of the same arguments put forward for *L. sebae* also apply to *L. punctulatus.*

There is no evidence of discrete spawning populations of *L. punctulatus* in WA. However, some old data suggest limited longshore mixing. When considered alongside other species in this region (e.g. *L. sebae*) for which there are more data on spatial dynamics, the limited data for *L. punctulatus* supports the regional fishery management unit boundaries in WA. Stock status in WA is thus assessed at the level of each of the fishery management units in Western Australia (i.e. Kimberley, Pilbara).

8.5 Assessment outputs - all three species

The case has been made above that the analysis and interpretation of the relevant otolith chemistry studies are now out-dated so consequently do not provide contemporaneous evidence of spatial separation at a level that would support a hypothesis of separate breeding populations. In support of this conclusion, evidence against the likelihood of separate stocks is provided by the continuous distribution of the three species along the NWS combined with their reproductive characteristics (prolonged breeding season) and propensity for egg/larval dispersal. Supplementary to the more direct consideration of these lines of information for stock structure, the certification assessment team considered that (reiterating from Section 3):

> *In addition to the evidence for stock separation within the Pilbara provided by otolith chemistry and by management responses to concerns about local stock depletion, the outputs from the stock assessment also indicate that it is inappropriate to regard the scalefish in the Pilbara region as a single stock. Trends in area-by area information from the integrated model (Appendix 5 of the assessment document) indicate*
>
> *differences between areas ("0", "West" and "East") for SSB, F and recruitment for both red emperor and bluespotted emperor. For Rankin cod (Appendix 8), the results for the different areas are more similar, but there are still differences, especially between Area 0 and the West and East areas.*

The following responses provide additional information to explain why the observed differences in assessment outputs cannot be used as evidence of separate stocks.

In terms of the differences in assessment outputs for fish in different areas, it is important to recognised that "reliable" catch rate data (i.e. trawl data) were available for the West and East areas, but not for Area 0 for which data were considered unreliable for a range of reasons. Our rationale for selecting only trawl catch rates (and not using trap catch rates) as indices of abundance includes:

- An issue with the trap catch rate data for the Pilbara fishery is that they are relatively coarse, i.e. calculated from monthly catch and effort statistics. In comparison, the trawl data are provided at a much finer resolution, i.e. for each day of each fishing trip, and are thus likely to provide more reliable measures of effort.

- The trends exhibited by the trap catch rates for red emperor and Rankin cod are far more volatile than the trawl catch rates. Given that these species are medium to long-lived, stock abundance would not be expected to change markedly from year to year, suggesting that other factors may be influencing the catch rate trends, e.g. unaccounted for variability in fishing efficiency.

- Trawling is an active fishing method (compared with trapping, which is passive), and each trawl covers a substantial area. In comparison, traps fish smaller discrete areas and thus trap data are unlikely to provide as good an abundance index as trawl data.

- When undertaking the model runs for the three species in the Pilbara there was no obvious tension between the catch rate and age composition data sets when the only catch rate data were from trawling. However, in preliminary runs for providing the revised set of results, i.e. prior to removing trap catch rates in Area 0, the model provided a poor fit to the trap catch rates in that area, suggesting inconsistency between the stock status signals for the Area 0 trap catch rate data and other data used in the model.

- Across the three species, the trap catch rates exhibit an increasing trend in certain periods, compared with stable or declining trawl catch rate trends. Thus, the use of only trawl catch rates will lead to more precautionary results than would be the case if both trapping and trawl data had been included.

Regarding the differences between the East and West areas, these variations are consistent with differences in historical trawl-effort intensity. The Western areas are closest to the home port and have higher historical and current levels of effort compared to the Eastern areas; these are more distant from port (i.e. increased fuel costs to operate further east). While spatial differences in assessment outcomes could be seen to support a hypothesis of spatially separated stocks, in this case the different patterns of historical trawl fishing confounds the evidence.

In summary, due to variability in fishing behaviour (methods, intensity) there is confounding of the data which precludes an interpretation of separate stocks.

9 Implications for assessment against the MSC standard

For the purpose of MSC certification, the stock structure of each P1 species is a potential issue so must be appropriately justified when defining the unit(s) of certification. The relevant guidance is provided in MSC Guidance for Fisheries Certification Requirements V2.0, October 2014 (page 24 - 25).

The three P1 species (*L. sebae*, *E. multinotatus* and *L. punctulatus*) under consideration for MSC certification in the NWS are considered to have similar stock structures and spatial dynamic patterns. In particular they each:

- are widely distributed both alongshore and across the continental shelf within the entire NWS region;
- have a high likelihood for bidirectional dispersal of their pelagic stages over the course of their extended spawning seasons;
- have no barriers to movement at any life history stage; and
- have a more or less continuous distribution of suitable habitat.

Commensurate with having extended pelagic dispersal of their eggs and larvae, spawning at any one location within the Pilbara region by each of the P1 species is likely to contribute to recruitment at the regional scale, not just the local scale. Consequently, these P1 species have characteristics that are consistent with an ‘isolation-by-distance’ model of stock structure. Due to the large range of each species, which not only extend across the entire NWS but also into Northern Territory, within the context of an isolation-by-distance model the precautionary approach that has been applied is to have a suitable level of spatial management that divides the NWS into Pilbara and Kimberley regions. This results in a management system that can impose spatially appropriate controls on fishing effort.

With respect to the MSC guidance on stock structure, the continuous habitat and distribution of these species across the NWS suggests that they do not constitute true metapopulations, which by definition requires that a population inhabit discrete patches. Furthermore, although continuously distributed, the lack of widespread mixing of adults of these species indicates that the populations are not fully panmictic, i.e. every adult does not have the opportunity to mate with every other adult (of the opposite sex) because they are isolated by distance. Nonetheless, the extended bidirectional flow of eggs and larvae means there is no simple source-sink relationship; rather, there is most likely to be connectivity via a continuum of “overlapping” sources and sinks and there is likely to be high levels of mixing among generations.

Given the appropriate consideration of:

- the patterns of stock structure (continuous distribution, isolation-by-distance, non-metapopulation, non-panmictic);
- the widespread distribution of these species;

- the large spatial scale of bioregions in northern WA;
- the high level of connectivity of the pelagic phases for these species within these bioregions, and;
- the generational time-scales of the three P1 species

The bioregion constitutes the most appropriate unit for the purposes of stock management. Therefore, the exploitation patterns, the assessment results and the impact of management measures applied at a bioregional scale are entirely consistent with the application of the MSC stock concept. It is also suitably precautionary and pragmatic.

In conclusion, managing these P1 species at a bioregional scale is not only the most efficient approach for such widespread species but it imposes no additional risks to the sustainability of their broader biological populations.

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Appendix A.

Table A1. Extract from MSC Guidance for Fisheries Certification Requirements V2.0, 1st October 2014 (page 25). Table G2 describes the level of assessment expected and considerations for scoring the stock outcome and harvest strategy components of a unit stock for a normal 'single population' stock (case A), and for three different forms of metapopulations (cases B, C and D).

Stock structure	**Description (degree of connectivity and self-recruitment)**	**Implications for management of the Stock (assessment of Outcome and Harvest Strategy)**
A. Single population	Completely isolated. Self-contained with no emigration or immigration of individuals from or to the stock. Occupies a well-defined spatial range and is independent of other stocks of the same species.	Whole population. Fishing on the population has no effect on the dynamics of neighbouring populations. Normal expectations may apply for reference points. The fishery must manage the stock above the point of recruitment impairment (PRI) to ensure recruitment is sustained.
B. Local population with partial isolation	Partially isolated and minimal connectivity. Self-sustaining. The degree of connectivity with other LPs in the metapopulation is so weak that, for management purposes, it can be considered a self-sustaining population. This may be true even if occasional larval exchanges between LPs are enough to maintain a certain degree of genetic flow and homogeneity.	Local population. Fishing on the local population appears to have no effect on the dynamics of neighbouring populations. Normal expectations may apply for reference points. The fishery must manage its own local unit stock above a point of recruitment impairment (PRI) to ensure recruitment is sustained. Requires information on the biology of the species, larval dispersal, source-sink dynamics, and oceanographic conditions supporting management at a local level. Information and uncertainties related to stock structure need to be scored in PIs 1.2.2, 1.2.3 and 1.2.4
C. Local population (s) with moderate connectivity within the metapopulation	Moderate connectivity. The degree of connectivity between LPs is enough to maintain genetic flow and some degree of homogeneity. Source-sink dynamics with variable degree of self recruitment. Sources of recruits act as core areas in the species range where the species occurs in all years and where the typical age composition exhibits regular recruitment patterns with multiple age classes present.	Local populations(s). Fishing on local populations affects the dynamics of neighbouring populations. Fishing and the management decision affecting upstream populations will have impacts on the components downstream. Local populations are not entirely in control of their productivity. The fishery must manage its own local unit stock above a PRI to ensure recruitment is sustained, but reference points also need to take into account connections with and dependences on neighbouring local

	There may be **sinks** where occasional individuals or low densities usually occur and where populations typically consist of only one or a few age groups, often of old individuals.	populations. Per recruit reference points (e.g., percentage spawners per recruit) may confirm the good management of the fishery to contribute to the wider surrounding populations. Separate monitoring of absolute reference points (either of incoming recruitment or of local population levels) may also be needed to confirm that the inputs of external recruitment are being sustained. Requires information on the biology of the species, larval dispersal, source-sink dynamics, and oceanographic conditions supporting management at local level. Information and uncertainties related to stock structure need to be scored in PIs 1.2.2, 1.2.3 and 1.2.4.
D. Local populations with maximum connectivity within the metapopulation	Maximum connectivity. Metapopulation is panmictic (mating is random within the entire metapopulation). Subpopulations are arbitrary. Well-mixed larval pool.	Whole metapopulation. Fishing on local populations affects the dynamics of neighbouring populations. The fishery must manage the whole metapopulation (unit stock) above a PRI to ensure that recruitment is sustained. Special attention may be needed in setting reference points to ensure that the LP structure is not impacted by fishing. Scored against the whole metapopulation. Information and uncertainties related to stock structure need to be scored in PIs 1.2.2, 1.2.3 and 1.2.4.