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Marine and Tropical Sciences Research Facility Milestone Report, October 2008

Program 7: **Halting and Reversing the Decline of Water Quality**

Project 3.7.1: **Marine and estuarine indicators and thresholds of concern**

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Summary

- This study is developing appropriate approaches to the evaluation of estuarine ecosystem condition in a tropical Australian context.
- The major (cast net) sampling of fish has been conducted as planned except for time lost early in 2008 due to severe flooding. This flooding also interfered with the collection of *Lutjanus russelli* for the assessment of individual condition, and meant gill net catches had very narrow taxonomic compositions and added little data to that available from cast nets. Gill net sampling was curtailed to prevent needless destruction of a substantial biomass of fish.
- Preliminary studies of nine estuaries provided a number of insights that provide considerable advances in the development of appropriate sampling and experimental strategies for evaluating estuarine ecosystem condition in the context of the unique ecological and physical attributes of north-eastern Australian estuaries.
- Except for interruptions due to adverse weather data for the main study have been collected every month from November 2007, with data up to September 2008 already analysed.
- Together the results of the preliminary study and the main study to date have produced considerable advances in understanding of the use of fish assemblages as indicators of ecosystem condition in tropical Australian estuaries. Notable they show that:
  a) The summary measures (e.g. total abundance, species richness) usually used to assess ecosystem health in similar habitats show little relationship to impact status, except where health is extremely degraded.
  b) Assemblage structures vary from estuary to estuary but variation is not predictable in terms of proximity, meaning it cannot be assumed that nearby estuaries can stand as appropriate controls for comparative studies.
  c) Consistent faunal patterns within individual estuaries over time indicate that a more appropriate approach for assessing environmental condition is to take advantage of this temporal consistency and use site-specific studies with the established pattern of change over time as the reference condition.

d) Clear seasonal changes mean that seasonality has to be factored in, with reference conditions needing to refer to particular points in time as well as to a specific estuary. This aspect will be addressed with the data currently being collected.
e) Estuary specific faunal patterns and seasonal changes are very robust. This is seen in consistent seasonal change across sites and the maintenance of site specific faunal patterns, despite samples analysed so far coming from the high recruitment season and despite extreme seasonal flooding with the potential to flush fish from the small estuaries sampled. Consequently, it should be possible to define optimal times to conduct studies to assess estuary condition. This surprising consistency also indicates that there is great potential in developing the use of process-specific variables as measures of estuary condition.

- Successful scavenging pressure studies indicate it has considerable potential as a measure of ecosystem condition, particularly when combined with other estuary specific approaches.
- Remaining field and laboratory work is well in hand, with most laboratory components finishing at, or shortly after, completion of field sampling.

Project Progress

Sampling

Initial studies were conducted in October 2007, using James Cook University Coastal and Estuary Ecosystem Ecology Group (CEEEG) funds, to investigate sources of variability in estuary fish fauna in the study area. These studies were used to focus site selection and sampling designs for subsequent sampling, and also contributed crucial understanding to inform the development of appropriate approaches to the evaluation of **estuarine ecosystem condition**.

Sampling proper commenced in November 2007, following development and approval of the Year 2 study plan, however extensive flooding of estuaries from late December 2007 to February 2008 necessitated substantial modification to all aspects of the study, as follows:

- Monthly cast net sampling aimed at collecting data for process level measures could not be collected from any sites in January and February 2008, and some sites in December 2007. However, full samples were collected in November 2007, March 2008, April 2008 and May 2008. Based on these samples, consistent patterns of temporal change were obvious, so because of the extreme time and logistic costs of monthly sampling subsequent sampling frequency was reduced to bi-monthly. Sampling continued in July 2008 and September 2008, and will continue on a bi-monthly basis until March 2008, weather permitting. This will produce a sequence of samples spanning two pre-wet and wet seasons, the parts of the year when the fish fauna are most variable (Sheaves 2006). Although the extreme wet season prevented the collection of the full sequences of samples in early 2008, this main sampling component for the collection of ecological process level ecological indicators has produced an extensive body of numeric data and samples for dietary and stable isotope analysis.
- The lack of a continuity of samples early in the study has also meant that stable isotope studies have had to be delayed until an appropriate series of samples is available. These will be available for processing in late 2008 to early 2009.

- Fish trap sampling in March 2008 for the collection of *Lutjanus russelli* (to be used as species-level indicators of health) showed extremely low catch rates at all sites indicating juvenile recruitment failure apparently due to the extreme flooding. This component of the study is therefore not viable in the conditions prevailing in 2008.
- Scavenging pressure studies could not be conducted during flooding, so development of this component was transferred to an alternative site.

Additionally, gill net sampling, aimed at extending the representation of trophic structure available from cast net sampling, was curtailed because of the narrow taxonomic composition sampled following flooding (essentially only mullet [Mugilidae] and catfish [Ariidae]) and the limited size ranges represented by these gears. It was considered that the small amount of trophic detail produced could not justify the death of a substantial biomass of fish using this very destructive gear. This contrasted with the high degree of taxonomic and size resolution produced from cast net sampling.

Project Inputs

Work inputs (excluding report writing, data analysis and planning): To date pilot sampling has involved 155 person field hours and 61 laboratory hours, cast net sampling 1,358 person hours, laboratory work-up of samples 1,445 person hours, gill net and trap sampling 92 hours. The additional costs above the MTSRF budget have been met from CEEEG funds and by involving an MSc student (unfunded) in the project to work on recruit persistence.

Project Outputs

Results for studies of recruit persistence and stable isotope analysis (including food web studies) have been delayed due to loss of data continuity but sufficient data are available to allow considerable advances in (a) understanding of appropriate sampling and experimental strategies for evaluating estuarine ecosystem condition given the unique ecological and physical attributes of north-eastern Australian estuaries, (b) understanding the limitations and use of fish community data in evaluating estuarine ecosystem condition, and (c) the development of process level variables as indicators of ecosystem health. These outputs come from two sources, (1) preliminary studies, and (2) the initial series of sampling in the main spatio-temporal evaluation of estuarine fish assemblages across a spectrum of levels of anthropogenic impact.

1. Preliminary Studies

1.1 Methods

The preliminary study involved sampling nine estuaries distributed in three coastal bays (Figure 1) within the study area that represented a cross section of estuaries that either had environmental attributes reported in the EPA Estuary Inventory or that could be estimated from a similar nearby site with reported environmental attributes (Table 1). The aims were (a) to investigate degree of similarity, degree of internal difference and if differences could be detected relative to available environmental variables, and (b) to focus site selection and sampling designs for subsequent sampling.

Additionally, a data set of fish assemblage structure from 21 estuaries in tropical northeastern Australia (Sheaves and Johnston in review) was interrogated allow investigation of the relationships between summary assemblage attributes (total abundance, species richness) and an index of “naturalness” (Angermeier 2000) developed for a panoply of 54 estuaries within the region. Briefly, naturalness was developed as a subjective index based on independent evaluation by each member of the CEEEG team who was experienced with most, or all, the 54 estuaries, using a Delphi approach (Rowe and Wright 1999). The output was a ranking ranging from the most pristine (Sandfly Creek on Orpheus Island) to the most highly modified (Curralea Lake, an estuarine lake constructed in the centre of Townsville's urban area as a pollutant trap) based on the degree of anthropogenic modification (Anderson 1991, Angermeier 2000).

Table 1: Environmental attributes reported in the EPA Estuary Inventory.

Catchment activities (%)	Proportion of pre-clear extent (%)	Naturalness (rank)	Contaminant exposure risk (rank)
Airports	mangrove	flow modification	sediment
Wetland	mudflat	number of fish barriers	nitrogen
Water reservoir	salt couch	naturalness estuary	phosphorus
Transport and communication	saltmarsh	naturalness catchment	pesticide
Irrigation and drainage	saltpan	habitat diversity	
Residential	estuarine vegetation cleared		
Irrigated sugar			
Mining			
Irrigated cropping			
Intensive animal production			
Industry			
Horticulture			
Grazing / natural vegetation			
Forestry			
Cropping			
Landfill			
Conservation and minimal use			
Catchment cleared			

Cast net fish assemblage data were analysed separately for species that spawn within estuaries and those that spawn offshore because spawning category is particularly influential in determining tropical estuarine fish assemblage structures (Sheaves *et al.* 2007, Sheaves and Johnston 2008) and these two groupings represent faunal components with spatial structure driven by fundamentally different processes (Sheaves in review). Analysis was conducted using multivariate regression trees (De'ath 2002) based on occurrence per ten cast nets.

1.2 Results

Both estuary (Figure 1) and offshore (Figure 2) spawning components of the assemblages of the nine estuaries showed **clear spatial assemblage structure**, although in both cases a relatively large component of variability remained unexplained. For estuary spawners (Figure 1) the primary tree split segregated a group of estuaries with high occurrences of four species, *Ambassis vachelli*, *Acanthopagrus berda*, *Zenarchopterus buffonis*, and *Ambassis nalua*, from a group of estuaries where only *A. vachelli* demonstrated high rates of occurrence. There was **a very strong reach split** in each group with upstream and downstream assemblages showing substantial differences.

A parallel situation is seen in the offshore spawner assemblage (Figure 2), with one group of estuaries differentiated on the basis of high occurrences of one species, *Leiognathus equulus*, and clear reach to reach differences. However, in this case **the grouping of estuaries is quite different** with the estuaries grouped together on the basis of estuary spawners segregated into different groups on the basis of offshore spawners.

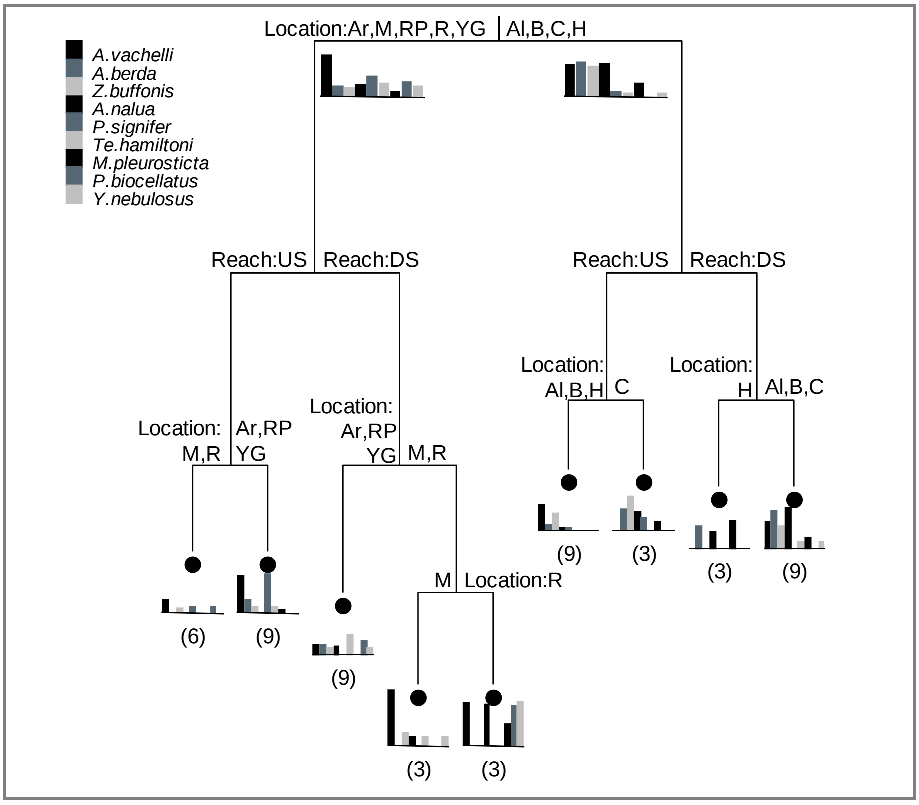


Figure 1: Multivariate regression tree for the effect of estuary locations and reach within estuary on the composition of the assemblage of fish that spawn within estuaries (species present in at least twenty percent of estuaries). Variability explained = 39%.

The environmental variable set had very little explanatory power. Both for estuary and offshore spawners, inclusion of the environmental variables in the analysis failed to change the model structure or increase the variability explained, and when spatial variables were excluded environmental variables explained only a small proportion of variability (Estuary spawners 18%, offshore spawners 11%).

The spatial structure of the full data set is well illustrated by MDS ordination (Figure 3). A clear faunal shift between downstream and upstream sites (indicated by arrows) is evident. Also evident is the *complex estuary to estuary spatial structure* characteristic of tropical eastern Australian estuarine fish assemblages (Sheaves 2006, Sheaves and Johnston in review); while the three estuaries from Cleveland Bay (diamond symbols) have broadly similar fauna (Figure 4) one of the three estuaries from both the other bays (Cleveland Bay, circles; Upstart Bay, squares) is distinctly different to the others, and shows a very different upstream gradient. This pattern is reflected in the species profiles for each estuary (Figure 4). The three Cleveland Bay estuaries have low occurrences of estuarine spawners and are dominated by one offshore spawner, *L. equulus*. In contrast, while two of the estuaries in each of the other bays have quite similar profiles the third is quite different.

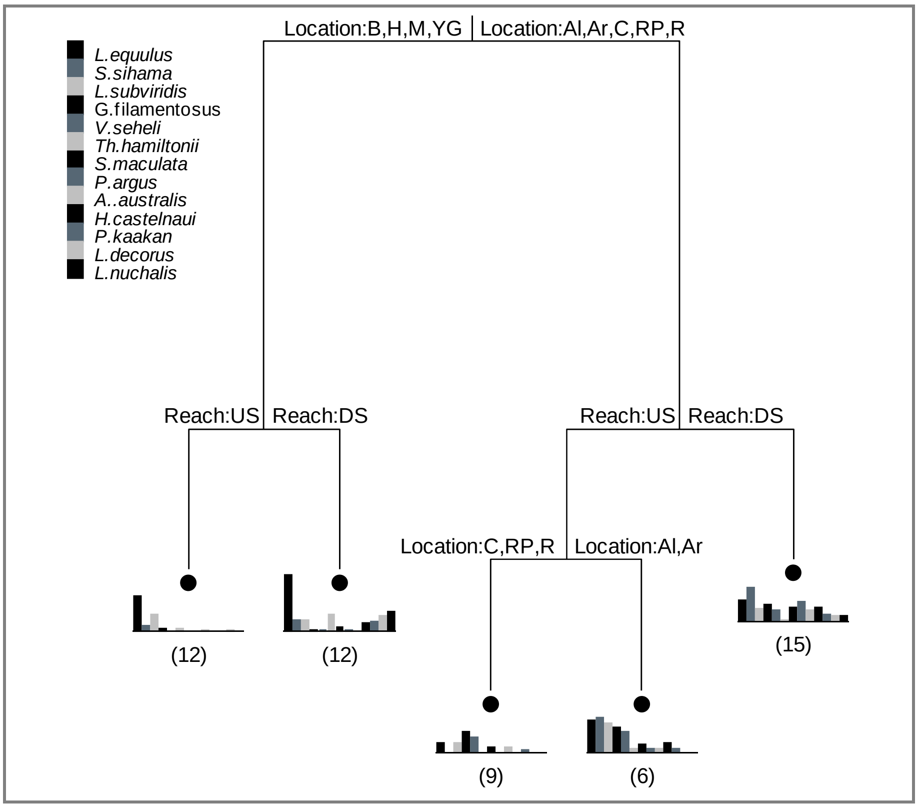


Figure 2: Multivariate regression tree for the effect of estuary locations and reach within estuary on the composition of the assemblage of fish that spawn offshore (species present in an least twenty percent of estuaries). Variability explained = 24%.

There was **no evidence of any clear pattern of change of summary fish assemblage attributes relative to the state of anthropogenic modification** across a broad diversity of North Queensland estuaries. When total abundance and species richness from the 21 in tropical Australia estuarine fish assemblages reported in Sheaves and Johnston (in review) was plotted against “naturalness”, neither variable showed any pattern of increase, as might be expected with increasing naturalness (Figure 5). In fact, if anything, there is a suggestion of declining richness as naturalness increases.

1.3 Discussion

The preliminary studies provided a number of insights that provide considerable advances in the development of appropriate sampling and experimental strategies for evaluating estuarine ecosystem condition in the context of the unique ecological and physical attributes of north-eastern Australian estuaries. They also reinforce understanding the limitations and use of fish community data in evaluating estuarine ecosystem condition, and provide the necessary base understanding for development and design of the main study.

1.3.1 Implications of spatial structure of fish assemblages

The fish fauna of the estuaries studied comprised a common suite of species typical of estuarine systems in the region (Sheaves 2006). Within this the clear estuary-to-estuary differences in fish assemblage structure expected in the low recruitment dry season (Sheaves 2006) were obvious. Previous studies (Sheaves 2006, Sheaves and Johnston in review) have shown that spatial factors, such as climatic zone or proximity of estuaries, have little influence on fish assemblage structure with substantial difference among even adjacent estuaries. The preliminary study data show greater than expected similarity among adjacent estuaries, particularly those in Bowling Green Bay, although this perception of difference largely reflects a difference in perspective to previous studies. Previous studies considered estuaries from a variety of regions and found estuaries within one “bay” were often more similar to those in other bays that they were to adjacent estuaries in the same bay. In contrast, the present study concentrates on the degree of similarity of adjacent estuaries within a bay, rather than comparisons of similarity with estuaries from other areas.

Although adjacent estuaries in Bowling Green Bay showed faunal similarities (Figure 4), this pattern was not consistent for all bays, with substantial differences both among corresponding reaches in different estuaries within a bay and in the extent of upstream faunal change. Furthermore, the similarities among estuaries in Bowling Green Bay, where faunas were most similar, were largely a reflection of low occurrences of most species compared to the other estuaries, with occurrences of “signature” estuary species, such as *A. vachelli* and *S. sihama*, actually varying greatly among Bowling Green Bay estuaries. Added to this is the fact that patterns of similarity among estuaries are different whether based on estuary or offshore spawners. This is important because the recruitment processes underpinning temporal variation in patterns of abundance of these two functional groups are fundamentally different meaning their occurrences and abundances will often vary independently over time (Sheaves in review). As a result faunal change will generally be driven by a complex interaction of internal estuarine and offshore drivers, meaning the fauna of any two estuaries is likely to vary in intricate ways leading to site-specific differences in patterns of temporal variation.

Taken together, the lack of consistency among adjacent estuaries, the variations in occurrences of crucial faunal components, and the different patterns of variation for different functional groups suggest that the idea of **a defined references condition is inappropriate for evaluating the condition or health of tropical estuarine fish assemblages**, and through them of the ecosystem as a whole, just as the **impact-reference site paradigm is unlikely to be suitable for evaluating change** in estuarine ecosystem condition.

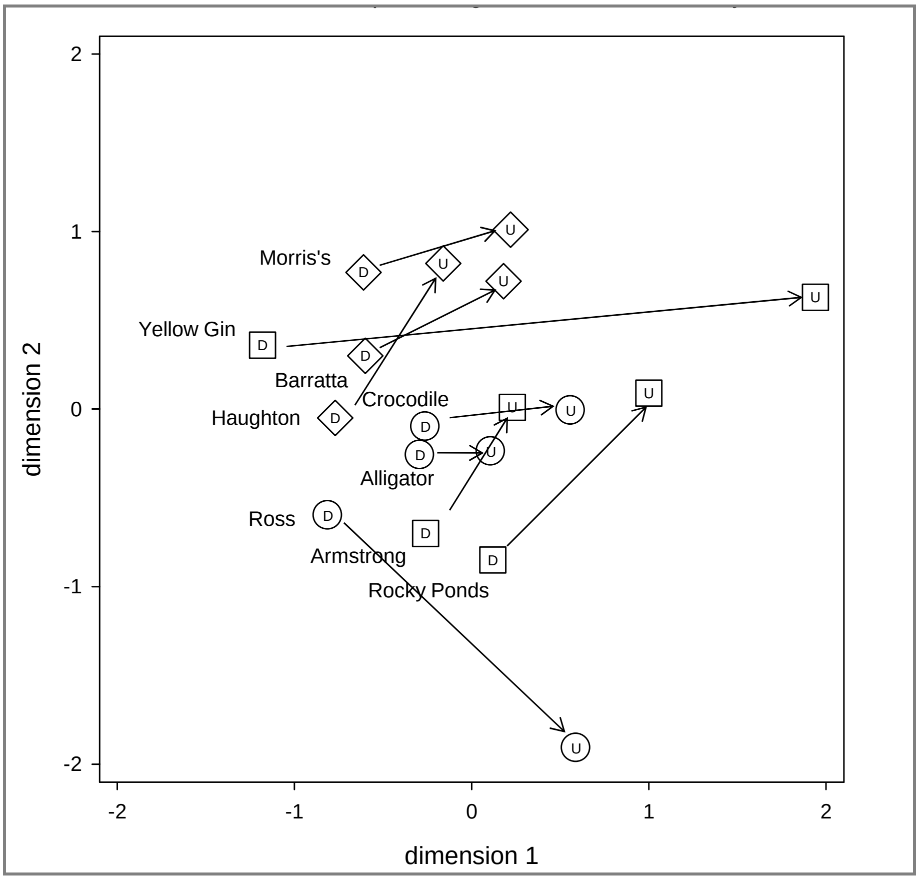


Figure 3: Non-metric multidimensional scaling of mean fish presences (per ten nets) from two reaches of nine estuaries. Based on Bray-Curtis Dissimilarities and square root transformed data. Stress = 0.13. U = upstream; D = downstream. Arrows indicate downstream-upstream gradient for each estuary.

1.3.1.1 Consequences for the design of future monitoring studies

In light of these considerations a more appropriate model for assessing the environmental condition of tropical estuaries based on fish assemblages includes:

1. Long-term site-specific studies taking advantage of known temporal consistency of site-specific fish faunal composition (Sheaves 2006), with the established pattern of change over time becoming the reference condition; and
2. Parallel long-term studies at control sites, with emphasis on evaluating similarities in the pattern of change between potential impact and control sites and using this to evaluate if changes at the potential impact site are outside the expected range of variation.

This design is appropriate for use with a range of dependent variables including both variables associated with faunal composition (e.g. measures of multivariate assemblage structure, species richness), and those aimed at evaluating the integrity of specific ecological processes (e.g. recruit persistence, phyto-detritivore dominance, phyto-detritivore: benthivore ratio, phyto-detritivore species richness and species composition, benthivore species richness and species composition, food web height, food web complexity, extent of onmivory and scavenging pressure).

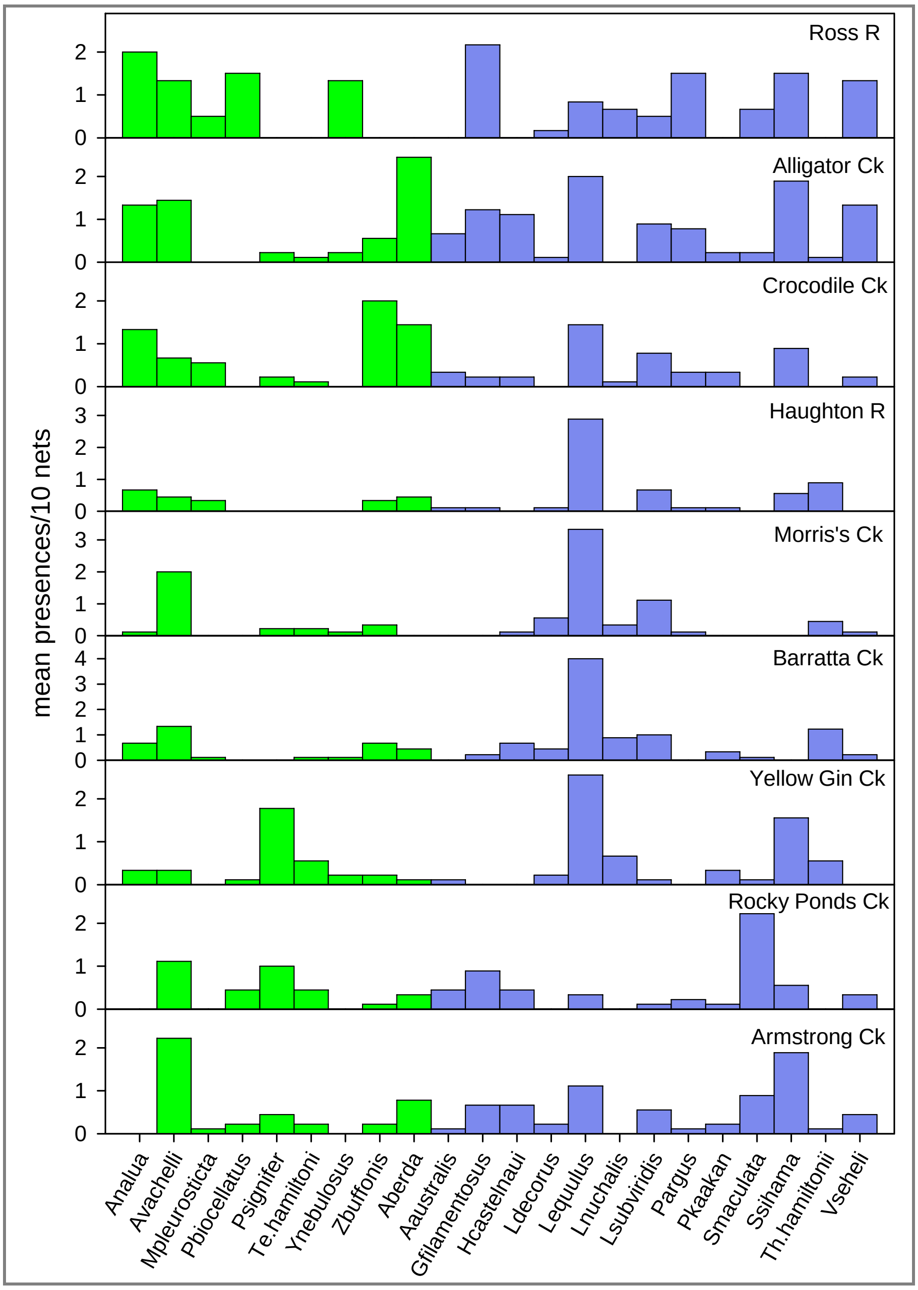


Figure 4: Profiles of presences of estuary (green bars) and offshore (blue bars) spawners in nine estuaries.

1.3.1.2 Knowledge gaps

Effectively utilising a study design based on site-specific monitoring requires detailed understanding of the drivers determining site-specific assemblage structure and ecological functioning, how these change over space and time, and a well developed knowledge of exactly what constitutes "similarity" of assemblage structure and ecological functioning.

1.3.2 Relationships to environmental valuables

The environmental variable set investigated for the nine preliminary study estuaries had very little explanatory power on their own, and added nothing to the explanation of variability beyond that provided by the spatial variables. This suggests that the levels of impact on the 9 estuaries were insufficient to produce detectable responses, at least using fish assemblage structure.

When the relationships between summary assemblage attributes (total abundance, species richness) and naturalness was investigated for 21 northeastern Australian estuaries there was no evidence of any clear pattern of change of summary fish assemblage attributes relative to the state of anthropogenic modification (Sheaves and Johnston in review). This implies that summary variables such as these do not provide the resolution necessary to detect differences in condition, except perhaps in extreme cases. Additionally, the lack of increases in the summary measures towards near pristine sites indicates that the idea that "pristine" sites can be recognised by having unusually high values of simple biological metrics is unrealistic in the case of tropical estuaries.

Together these results indicate that the main study should (a) evaluate sites demonstrating a more extreme range of potential impacts, and (b) concentrate on a range of process level variables in addition to faunal composition.

1.4 Implications for the main study

The results of the preliminary study have a range of implications for the design of the main spatio-temporal evaluation of estuarine fish assemblages across a spectrum of levels of anthropogenic impact.

- The complexity of fish faunal assemblages that are characteristic of tropical estuaries suggests that composition alone is unlikely to provide for sensitive evaluation of ecosystem condition. Rather there is a need to investigate a range of process level variables. Likely candidates are: *recruit persistence, phyto-detritivore dominance, phyto-detritivore: benthivore ratio, phyto-detritivore species richness and species composition, benthivore species richness and species composition, food web height, food web complexity, and the extent of onmivory.*
- The substantial levels of within-estuary spatial variation detected means that the estuaries used to evaluate these variables need to be physically small enough to allow the whole fauna to be represented. This is particularly important for the accurate representation of size structures (for recruit persistence and trophic variables).
- Estuaries selected for study need to represent a range of degrees and types of anthropogenic impact. Identifying these is difficult because there have been no comprehensive evaluations of extent of anthropogenic impact that includes smaller estuaries in the study area. However, although subjective, the recently developed naturalness index does provide a clear basis for such a selection.
- The lack of influence of environmental variables in the preliminary studies underlines the importance of specifically including estuaries with known high levels of anthropogenic impact. Including a wide range of levels of impact will enable the sensitivity of candidate variables to be evaluated.
- A range of types of impact need to be represented in the set of study estuaries to provide the opportunity of evaluating the sensitivity of particular candidate variables at detecting specific categories of impact.

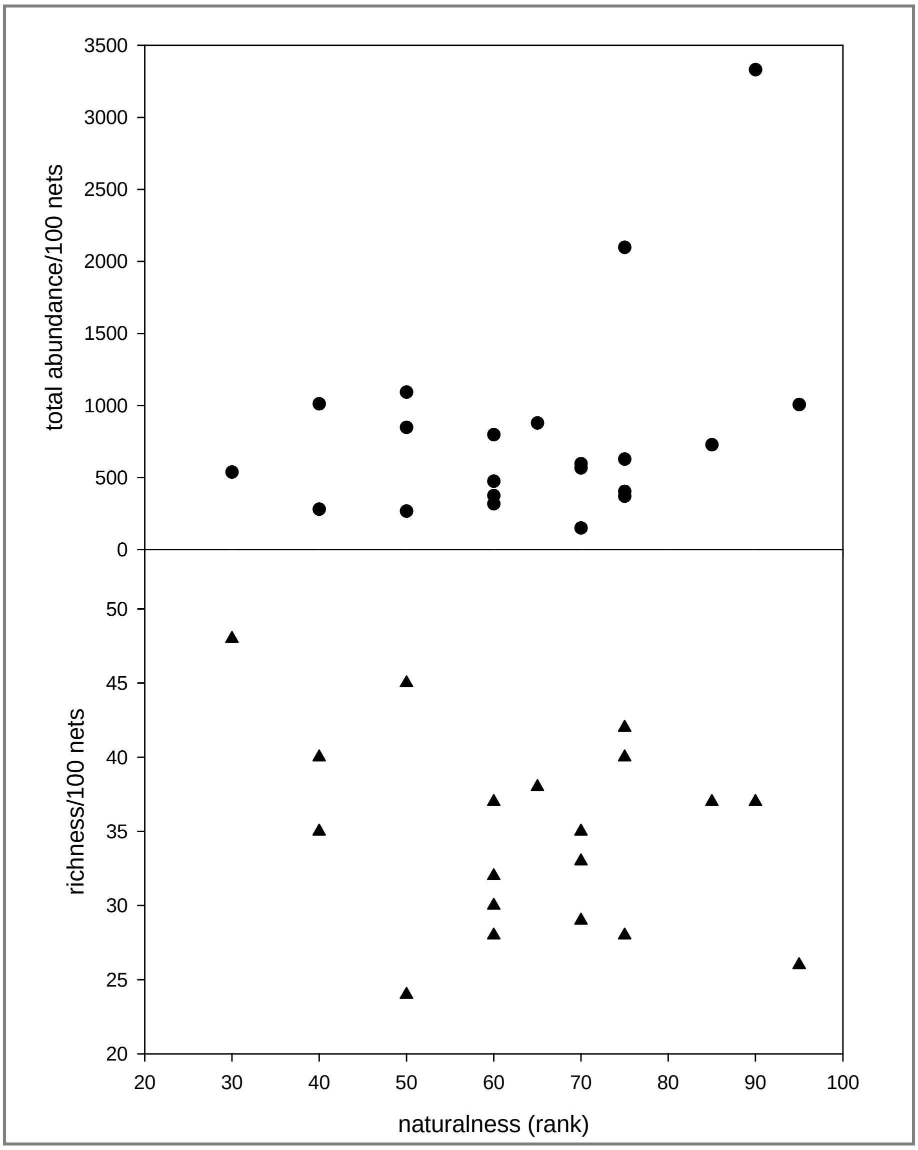


Figure 5: The relationship between naturalness and (a) total abundance / 100 nets; and (b) richness / 100 nets, for 21 North Queensland estuaries.

2. Spatio-temporal evaluation of estuarine fish assemblages across a spectrum of levels of anthropogenic impact

2.1 Methods

Eleven "estuaries" were included in the spatio-temporal evaluation. They were selected to be physically small enough (maximum five kilometres' navigable length) to allow the whole fauna to be represented. For logistic and cost reasons the estuaries were all located in the dry tropics region in the Townsville-Burdekin area. The estuaries were selected to represent a range of potential human impacts. Cocoa, Crab and Doughboy Creeks have little potential human impact besides low levels of fishing and boating, very restricted exposure to light urban development (only Crab and Doughboy) and minor exposure to light cattle grazing. Hell Hole and Insulator Creeks have moderate exposure to sugarcane farming, with sugar grown in about fifty percent of their catchments. Mud Creek has substantial exposure to sugarcane farming, with sugar grown around most of its perimeter and most of its seasonal freshwater input modified by the imposition of dams and levees. Bluewater and Healy Creeks are exposed to moderate impacts with light urban and low intensity farming adjacent to them and in their catchments. Sandfly Creek has a sewage outfall at its mouth but little other exposure. Curralea and Paradise Lakes are "constructed "estuaries in Townsville City's urban area, and are heavily exposed to a range of pollutants. Both The Lakes were constructed as "pollution traps" and have a history of fish kills, usually attributed to anoxic conditions. They have restricted water exchange with Ross Creek, their feeder estuary, and are fed by a series of drains leading from Townsville's urban and industrial areas.

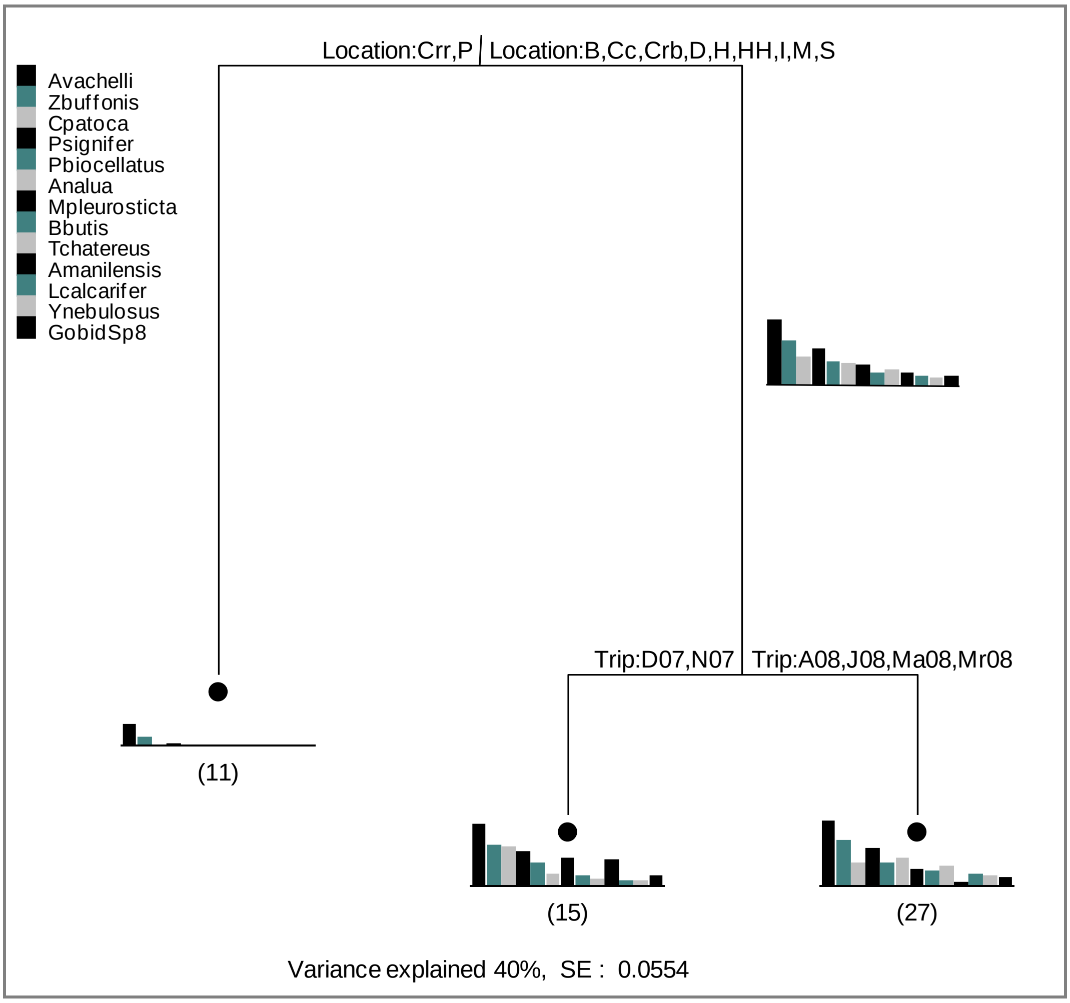


Figure 6: Multivariate regression tree for occurrences of estuary spawning fish.

Cast net samples were collected from each estuary on a monthly basis. This periodicity was employed to provide detailed data on spatio-temporal patterns of faunal change, abundance and species richness, size structure and recruitment, and trophic dynamics. Sampling commenced in November 2007 but was interrupted in January and February due to extreme wet-season flooding. Flooding also prevented sampling in two of the sites, Mud and Sandfly Creeks in December 2007. Sampling has been conducted through to October 2008 and is continuing. Data from November 2007, December 2007, March 2008, April 2008, May 2008, and July 2008 are fully sorted and identified and are presented here. Data analyses are confined to faunal composition because other parameters require a complete time series to be relevant.

Samples were collected from an aluminium dingy (4.5m), powered by an electric motor. Cast netting was conducted haphazardly with the aim of representing the entirety of each estuary as completely as possible. Initially, twenty percent more net samples were collected that considered necessary on the basis of previous studies: Bluewater 20, Cocoa 60, Crab 60, Curralea 30, Doughboy 55, Healy 30, Hell Hole 90, Insulator 60, Mud 60, Paradise 30, and Sandfly 42. Data analysis from the first two sampling trips indicated that fewer nets were required, so the numbers of net samples collected were reduced to optimise sampling effort: Bluewater 20, Cocoa 45, Crab 45, Curralea 30, Doughboy 45, Healy 30, Hell Hole 60, Insulator 45, Mud 45, Paradise 30, and Sandfly 40.

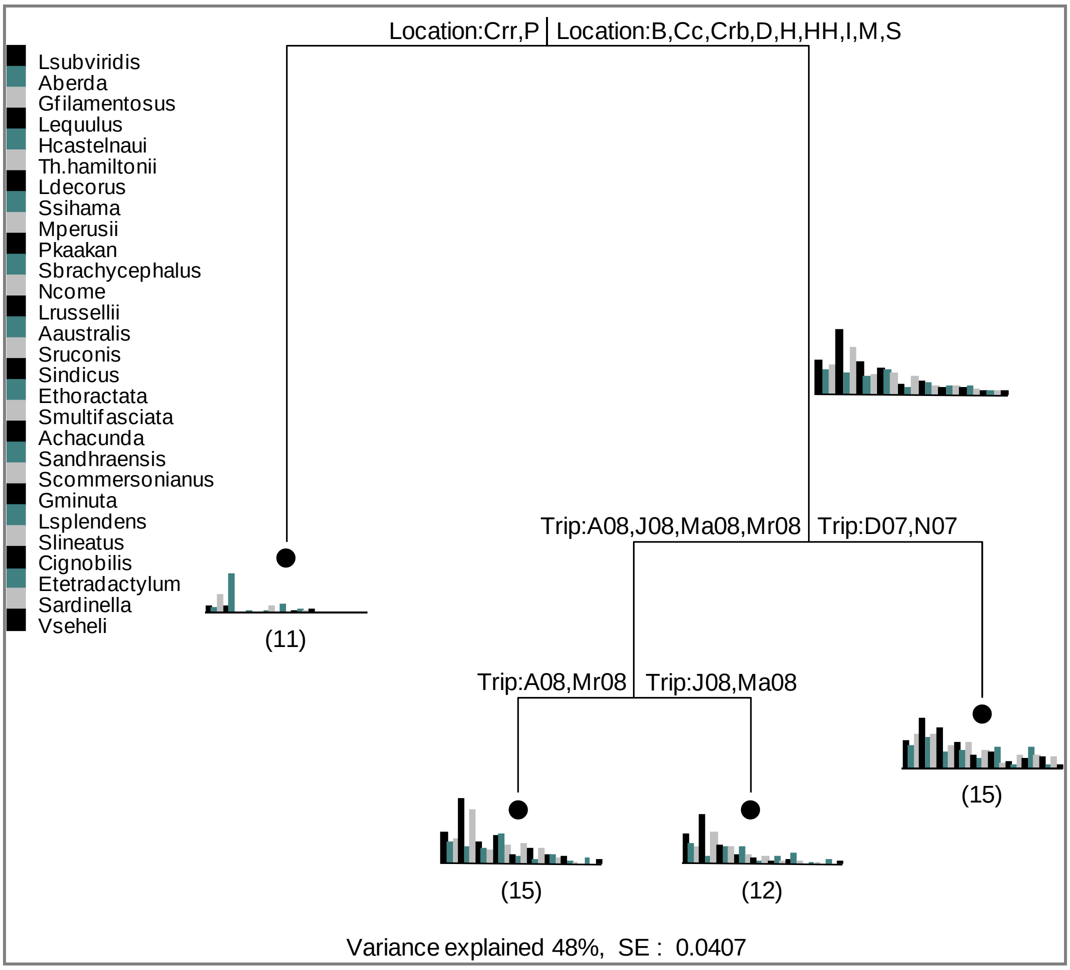


Figure 7: Multivariate regression tree for offshore spawning species.

Cast net data were analysed both as CPUE per one hundred nets and number of occurrences (i.e. presences) per one hundred nets. The two approaches produced almost identical results so only results of the more robust occurrence analysis are presented except where CPUE is explicitly required. All data analysis was conducted on species present in more than twenty percent of the estuary by trip combinations, and the occurrence data square root transformed to improve the distribution of residuals. Data for estuary and offshore spawning species were analysed separately using multivariate Classification and Regression Trees (mCARTs) (De'ath 2002) with estuary and trip as explanatory variables. Data for both estuarine and offshore spawners were combined and multivariate patterns explored using Hierarchical Cluster Analysis, based on Bray Curtis similarity, with the

Simprof procedure (Clarke and Warwick 2001) used to define coherent multivariate clusters. The results were further analysed and displayed as MDS ordinations.

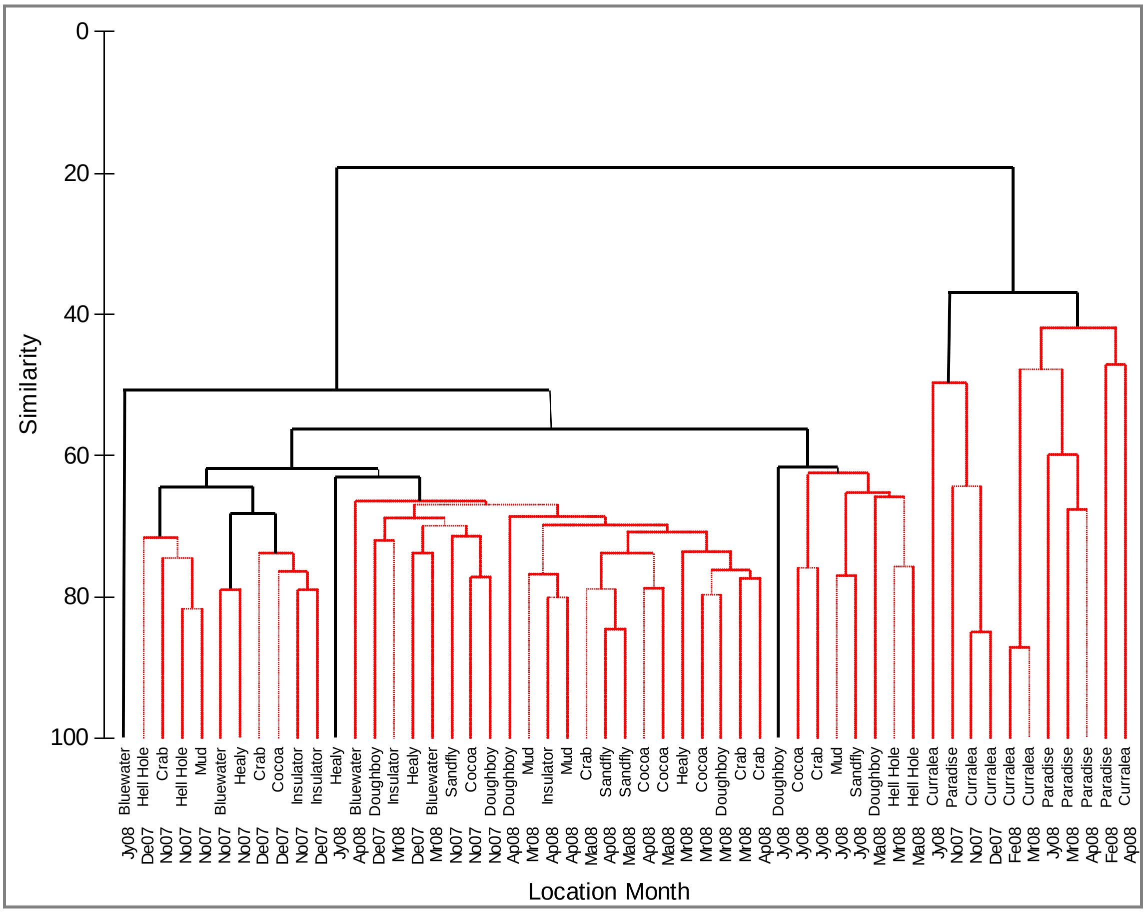


Figure 8: Cluster analysis for fish occurrences for eleven estuaries. Black branches indicate coherent groups (Simprof. $P<0.05$).

2.2 Results

Together, November, December, February, March, April, May and July cast net samples comprised 161,170 fish from 123 species, including thirty estuary spawning species and 93 offshore spawners. Most were juveniles (to <5mm FL), with strong recruitment, particularly during November and December prior to flooding, but to a lesser extent in March.

Estuary spawning species were almost totally absent from Curralea and Paradise Lakes (Figure 6), clearly distinguishing these sites from all others. The other sites formed a large homogeneous group that could be differentiated temporally, with samples from November and December 2007 distinct from the 2008 samples.

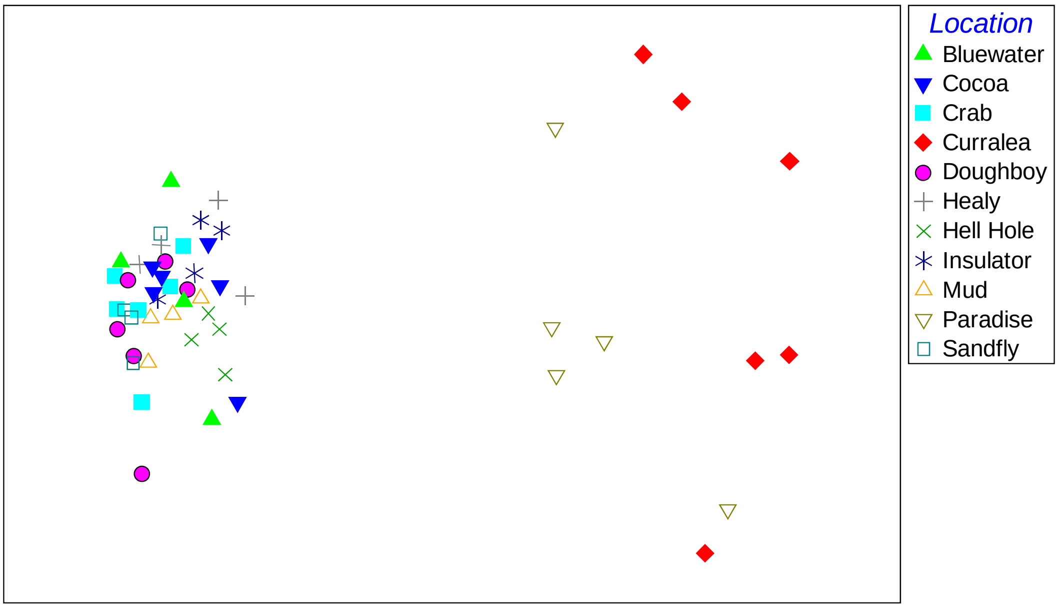


Figure 9: MDS (Stress = 0.09) of fish occurrence in all eleven estuaries over six months.

Curralea and Paradise Lakes again had a much attenuated offshore spawner assemblage (Figure 7) although some of these, such as *Herklotsichthys castelanui* were notably more common than the estuary spawners. The remaining samples were separated by trip rather than location, with November and December 2007 samples differing from March and April 2008 samples, which were again different from May and July 2008 samples. This consistent pattern of change was a reflection of gradual reductions in occurrences of most species.

Hierarchical cluster analysis of the whole data set (Figure 8) emphasised that Paradise and Curralea Lakes samples were clearly different to all other estuaries regardless of time. Simprof analysis (Figure 8) showed clear groupings (P<0.05) mainly relating to the split between the Paradise and Curralea samples, and a temporal trend at the other locations. This pattern is clear in the MDS ordination with the Curralea and Paradise appearing as multivariate outliers compared to the cluster of points for the other samples (Figure 9). When MDS is conducted without the Curralea and Pardise “outliers” (Figure 9), a broadly similar overall pattern of change is evident (Figure 10).

There was little clear relationship between CPUE and naturalness (Figure 13a), besides some suggestion of increased variability in the more natural systems. In contrast, there seems to be a strong relationship between richness and naturalness but in reality richness is only depressed in the highly degraded Curralea and Paradise Lakes (Figure 13b). There is no clear relationship between richness and CPUE (Figure 12), and no ordering of either parameter by the type of impact, except in the extreme situations of Curralea and Paradise Lakes.

Plots of proportional CPUE / 100 nets against rank abundance (Figure 13) show a range of patterns of dominance. Paradise and Curralea Lakes again stand out, but more because of their lack of species than the shape of their relationships. Putting these aside, although there are a variety of different patterns of dominance, there is little clear indication that there is any ordering to the patterns related to the potential impact status of the estuaries. In fact, perhaps the largest temporal variation in dominance was at Crab Creek, one of the systems with the least potential for impact.

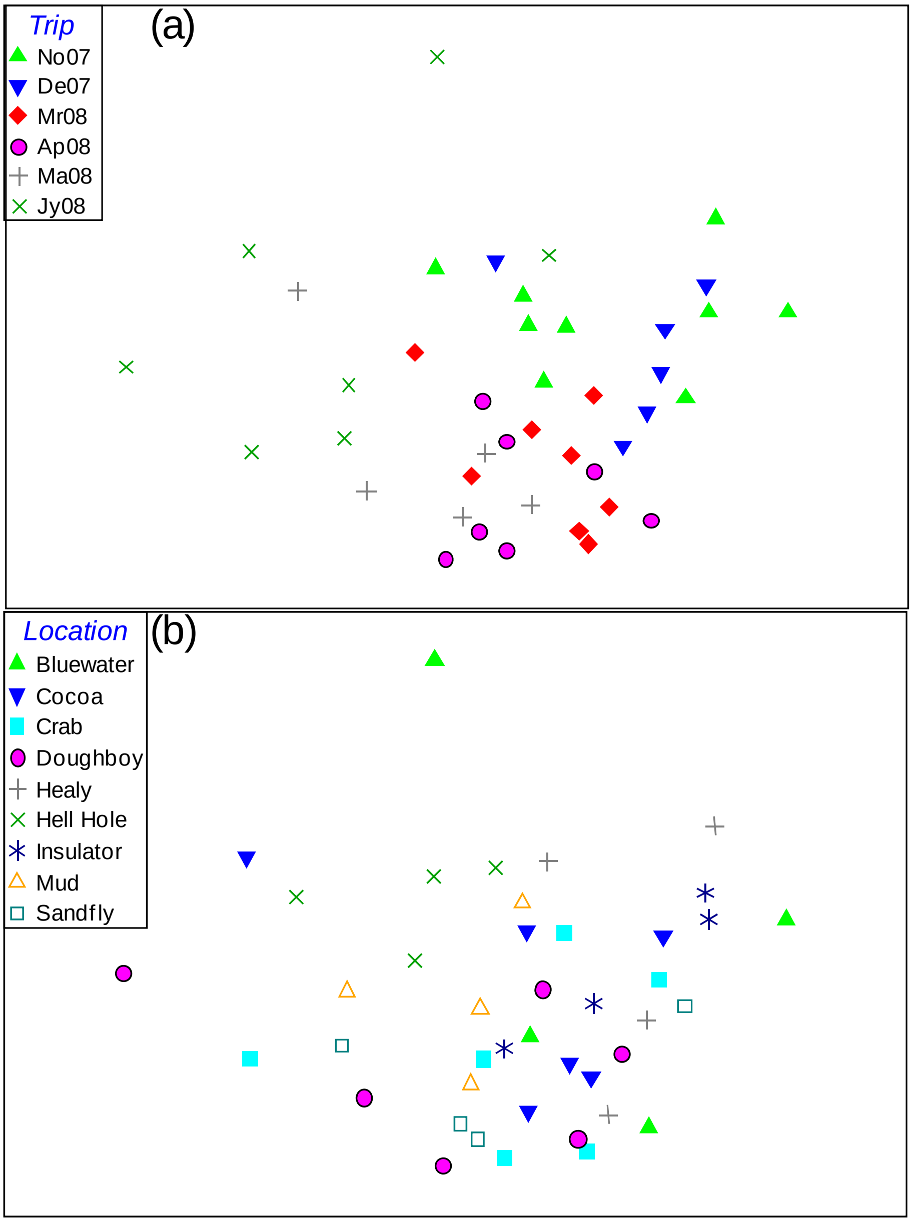


Figure 10: MDS (Stress = 0.18) of fish occurrences in nine estuaries over six months. The extremely different Curralea and Paradise Lake samples have been omitted to allow investigation of the patterns of change at the other locations. Coded (a) by trip; and (b) by location. The large arrow in (a) indicates the general trend in change over time.

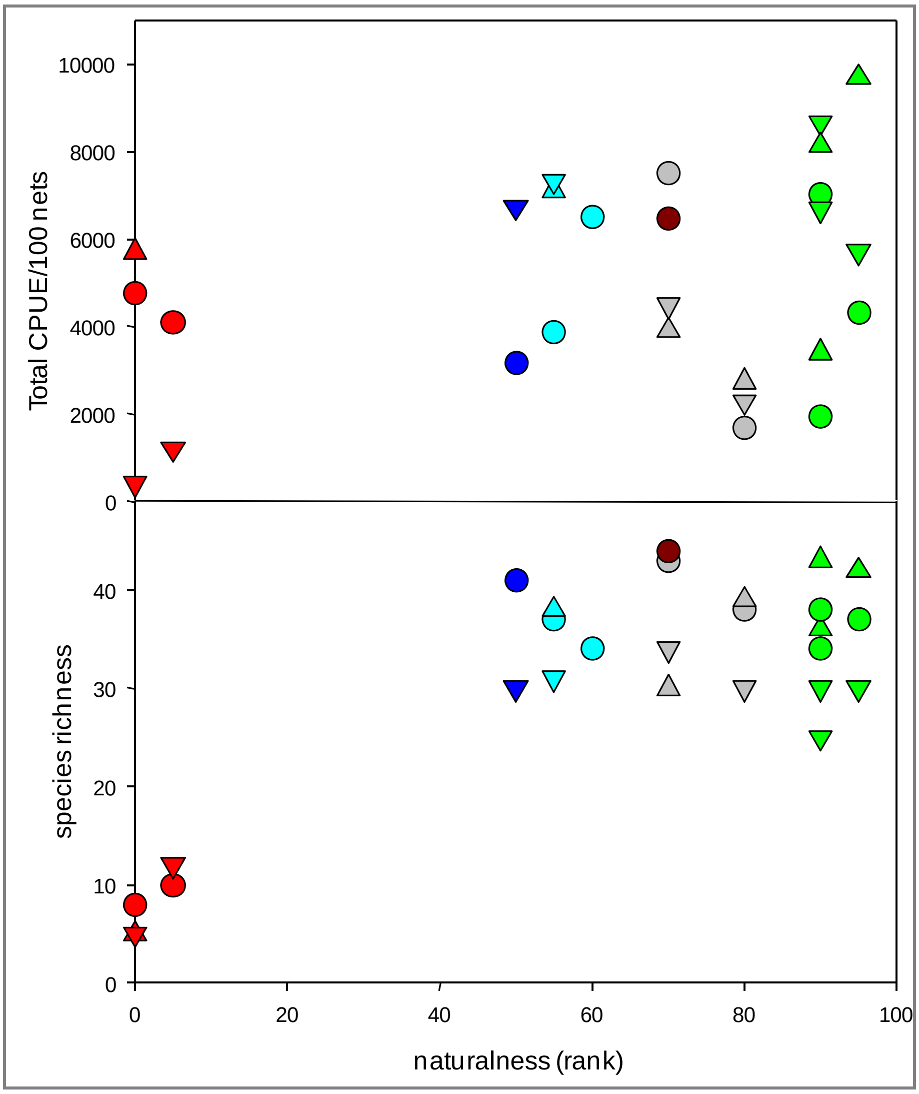


Figure 11: The relationship between naturalness, and CPUE and species richness for eleven estuaries over three months. Colours: Green = little human impact (Cocoa, Crab, Doughboy); Grey = moderate sugarcane (Hell Hole, Insulator); Blue = substantial sugarcane (Mud); Aqua = light urban / farming (Bluewater, Healy); Brown = sewage (Sandfly); Red (Lakes, urbanised artificial). Symbols: Circles = November; Triangle (up) = December; Triangle (down) = March.

Estuary species profiles (Figures 14-17) show that all the estuaries, except Curralea and Paradise Lakes, possess broadly similar faunas. Additionally, clear patterns of seasonal change are obvious across most systems. For example:

- *Ambassis vachelli* occurrences increased continually over time in all estuaries except Cocoa Creek where occurrences remained fairly consistent;
- *Leiognathus equulus* occurrences were low in November and peaked in March in most estuaries;
- *Thryssa hamiltoni* occurrences increased over time at most sites;
- Occurrences of the detritivores, *Moolgarda perusii* and *Nematalosa come*, declined over time in most estuaries; and

- *Selonatoca multifasciata* showed a small, but consistent, recruitment pulse across most estuaries in March.

Despite the possession of generally similar fauna and the presence of similar patterns of seasonal change, there were consistent site to site differences in species profiles, with both assemblage structure and overall numbers of occurrences more consistent within an estuary over time than between estuaries at any one time.

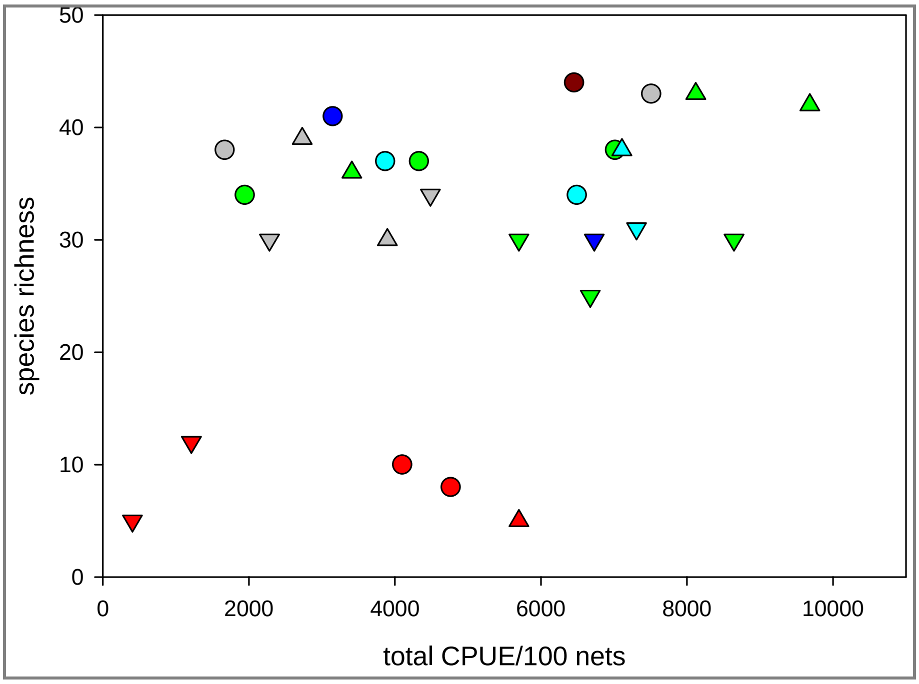


Figure 12: Relationship between species richness and total CPUE for eleven estuaries over three months.

2.3 Discussion

The large body of data analysed so far only represents the initial component of the much larger data set still being amassed. Much of the detailed information (recruitment patterns and recruit persistence, trophic group analysis) will not be useful until the complete data sets are available. However, the analyses conducted so far add considerable emphasis to the understanding developed in the preliminary study.

Including, estuaries with a broad range of levels of potential impact showed relationships between “naturalness” common summary statistics, like total CPUE and species richness, not detected in the preliminary study. However, the relationships were only obvious in the extreme situation of the heavily impacted Curralea and Paradise Lakes that stood out as outliers in every analysis. For less potentially impacted sites no relationships were apparent. **It seems clear that simple summary statistics like these are of relatively little use for detecting anything but the grossest impacts in northeastern Australian estuaries**. This seems to be at least partially a result of tropical estuaries dispossessing fish fauna naturally adapted to a stressful, fluctuating environment (Sheaves in review).

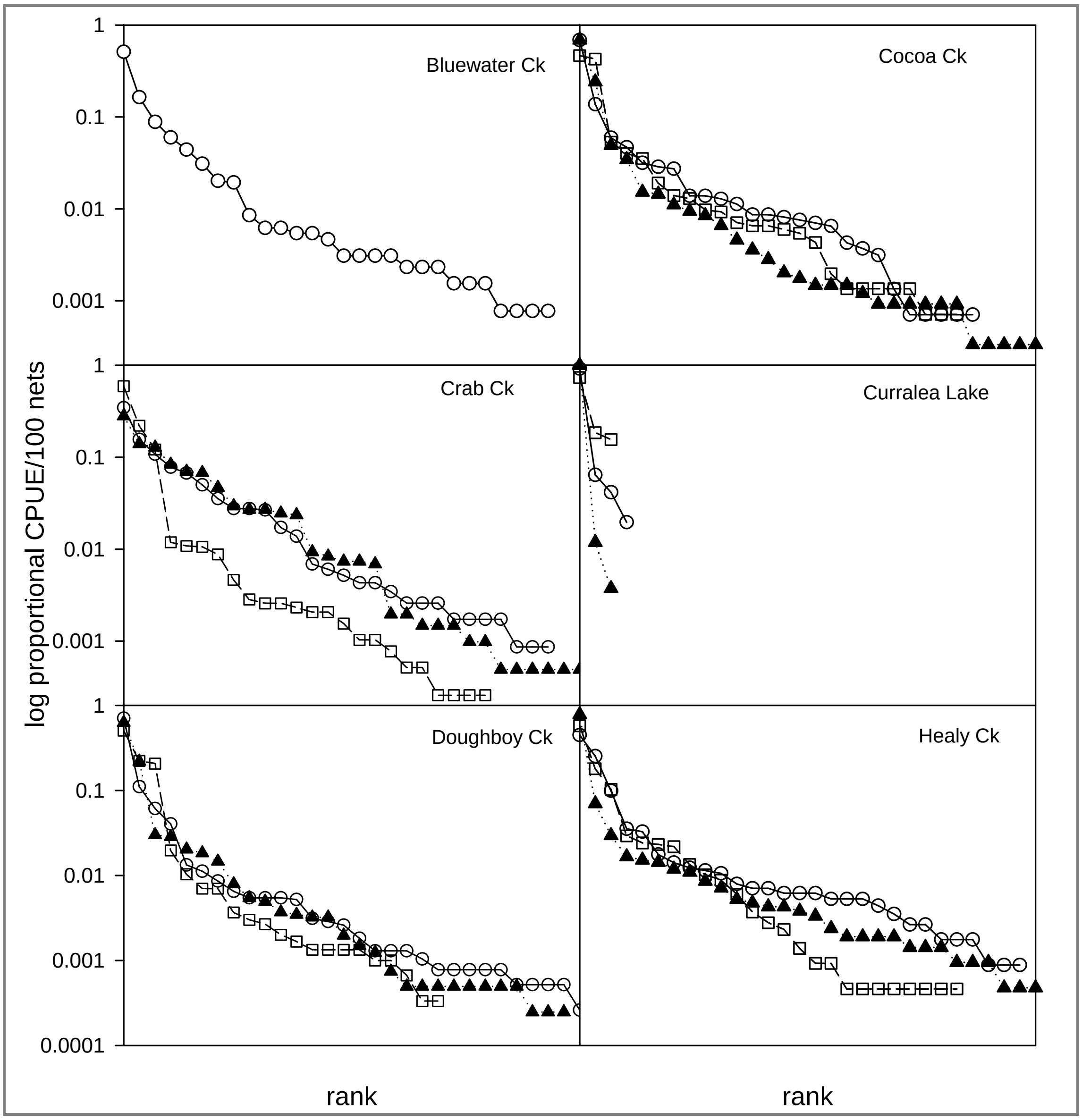


Figure 13a: Log proportional CPUE vs. species rank plots for six estuaries. Symbols: Circles = November; Filled triangles = December; Squares = March.

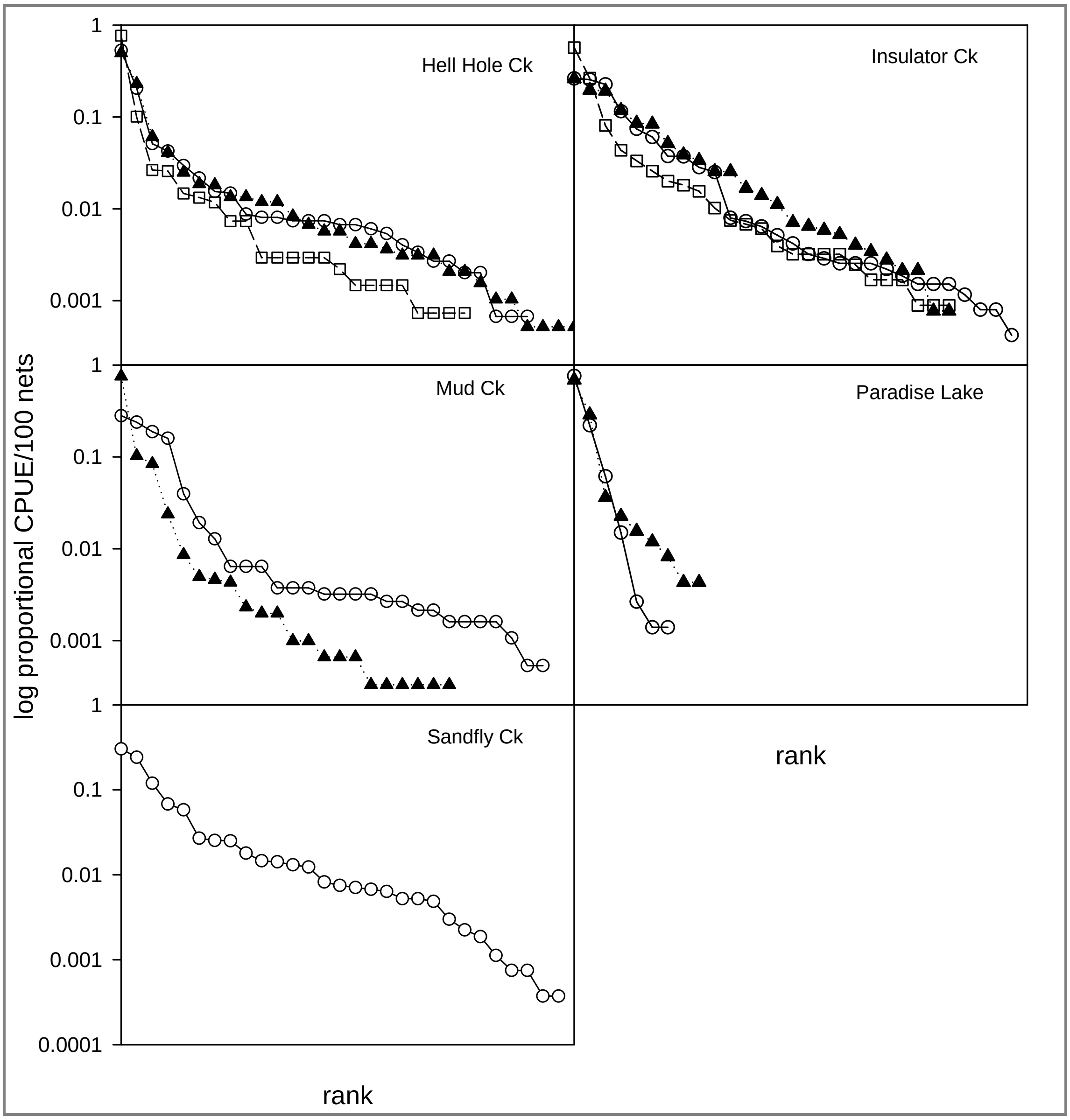


Figure 13b: Log proportional CPUE vs. species rank plots for five estuaries. Symbols: Circles = November; Filled triangles = December; Squares = March.

Although Paradise and Curralea Lakes are distinct from all other estuaries in a variety of ways, one difference is particularly telling; the very low occurrence of estuary spawners strongly implies a lack of *in situ* reproduction. This in turn suggests that reproductive and recruitment success may provide sensitive measures of estuarine ecosystem health, once their spatio-temporal patterns and variability are understood.

The lack of systematic similarities in such parameters as CPUE, species richness, assemblage structure and faunal dominance, reinforces the difficulty of implementing traditional impact-assessment sampling designs based on “impacted” and “control” sites. Although northeast Australian estuaries possess a common fish fauna, estuary to estuary differences make it unlikely that anything less than a major impact could be reliably detected using such an approach. However, the maintenance of consistent faunal patterns within individual estuaries over time indicates that a more appropriate approach for assessing environmental condition is to take advantage of the known temporal consistency of site-specific fish faunal composition (Sheaves 2006), with the established pattern of change over time becoming the reference condition. However, the clear patterns of seasonal change emerging from this study need to be factored in; reference conditions need to refer to particular points in time as well as to a specific estuary.

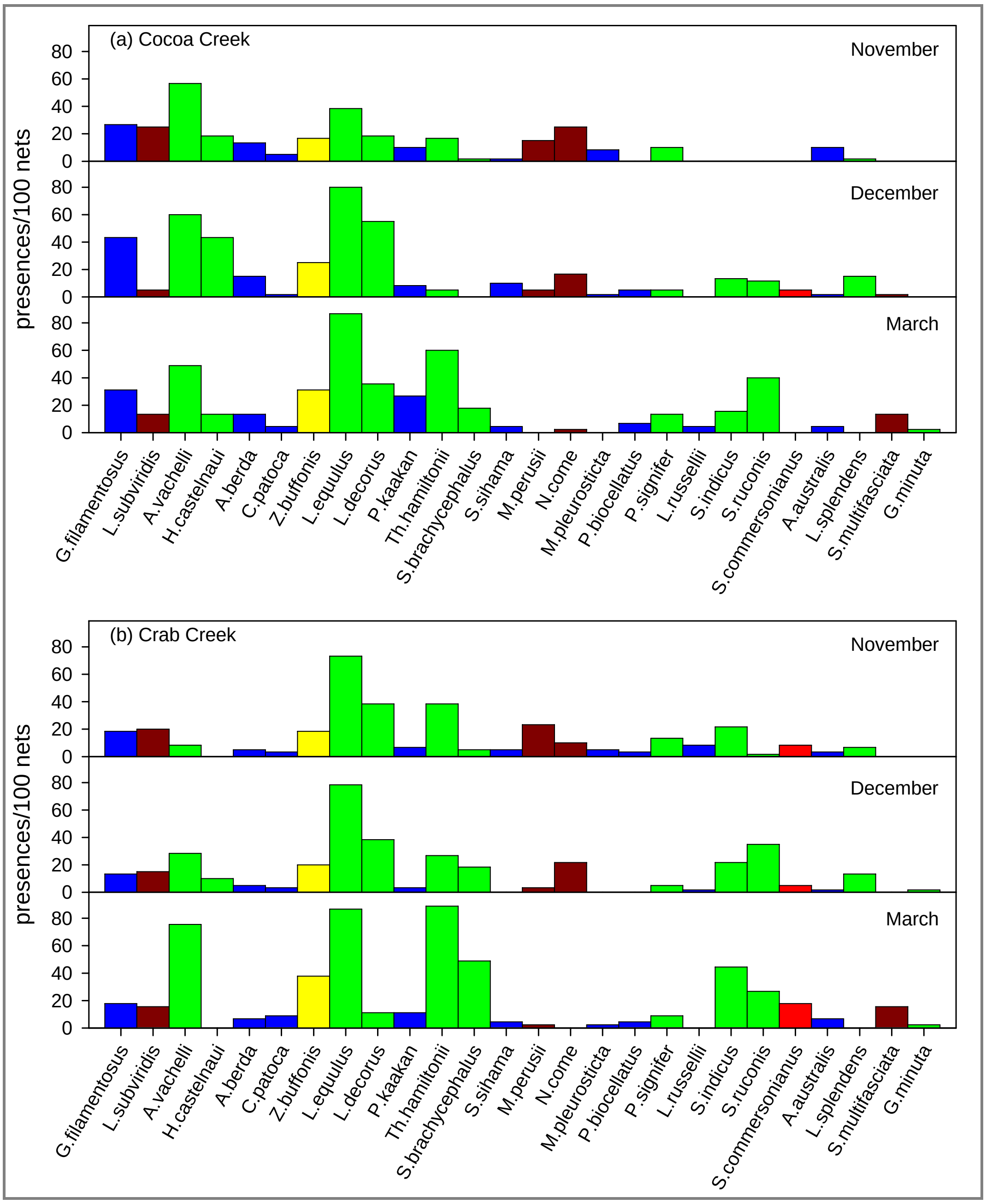


Figure 14: Species profiles for (a) Cocoa; and (b) Crab Creeks.

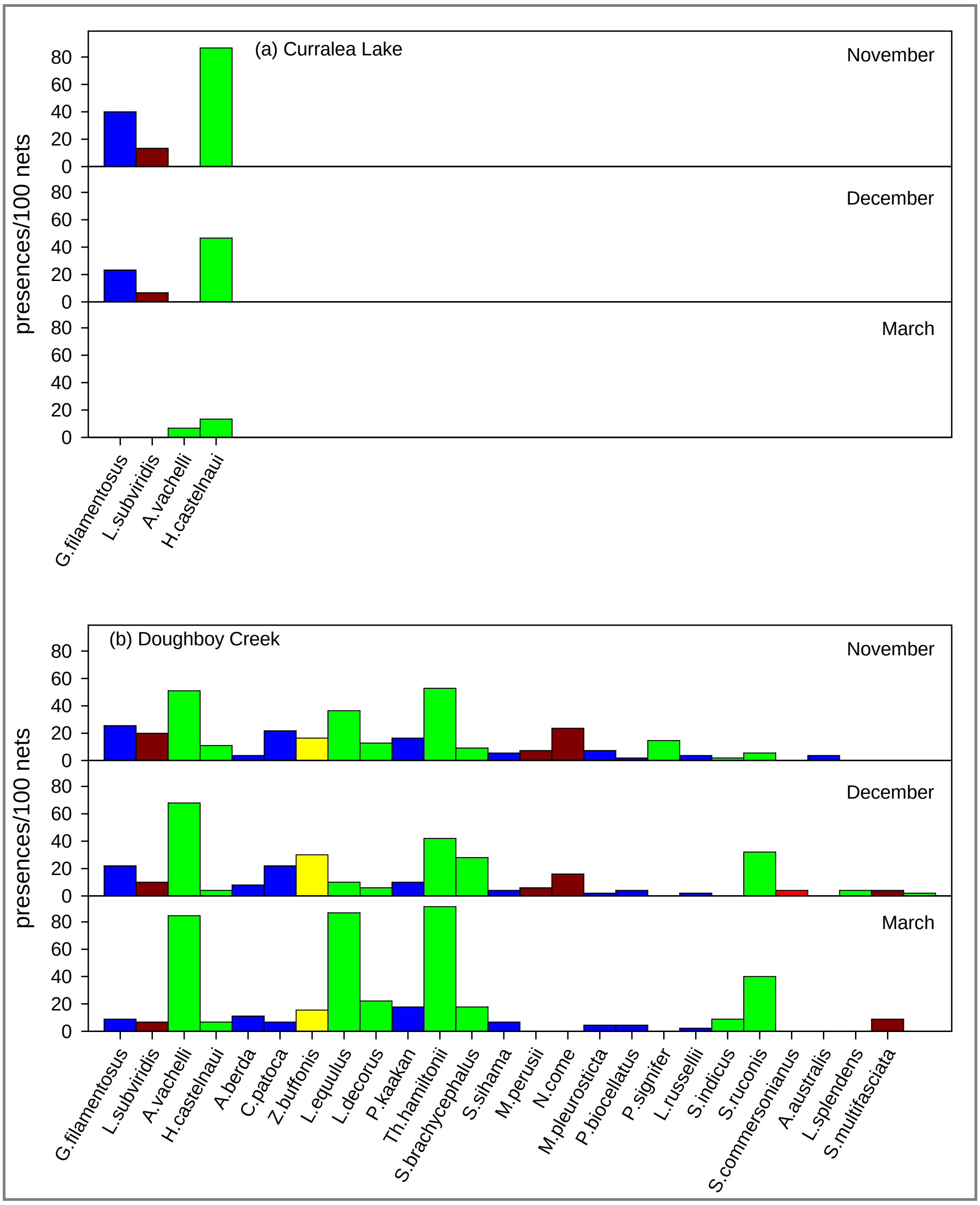


Figure 15: Species profiles for (a) Curralea Lake; and (b) Doughboy Creek.

Surprisingly, seasonal change was consistent across sites and site specific faunal patterns were maintained despite extreme seasonal flooding with the potential to flush fish from the small estuaries sampled. This strongly suggests that both estuary specific faunal patterns and seasonal changes are robust meaning it should be possible to define optimal times to conduct studies to assess estuary condition. This surprising consistency also indicates that there is great potential in developing the use of process-specific variables as measures of estuary condition.

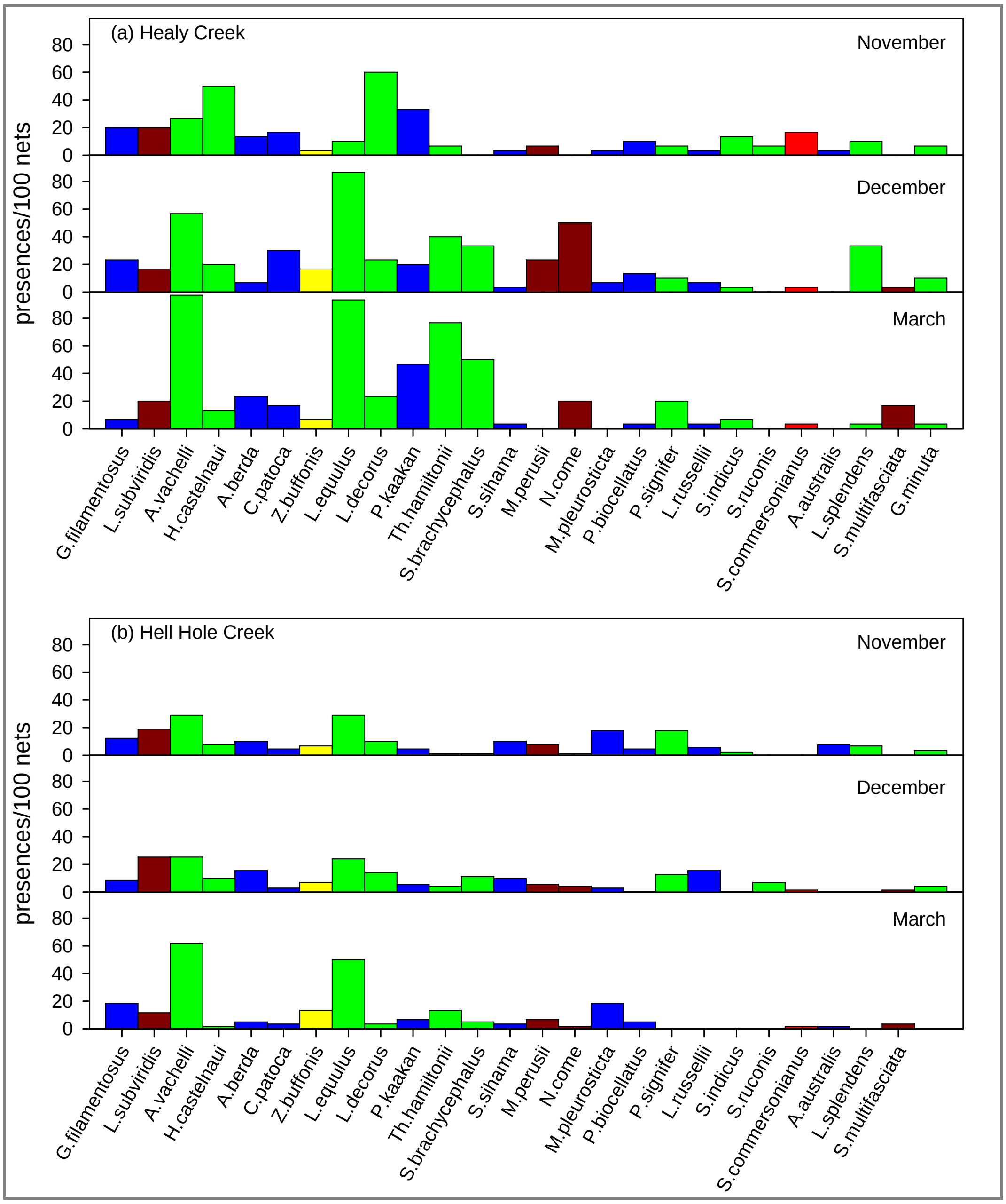


Figure 16: Species profiles for (a) Healy; and (b) Hell Hole Creeks.

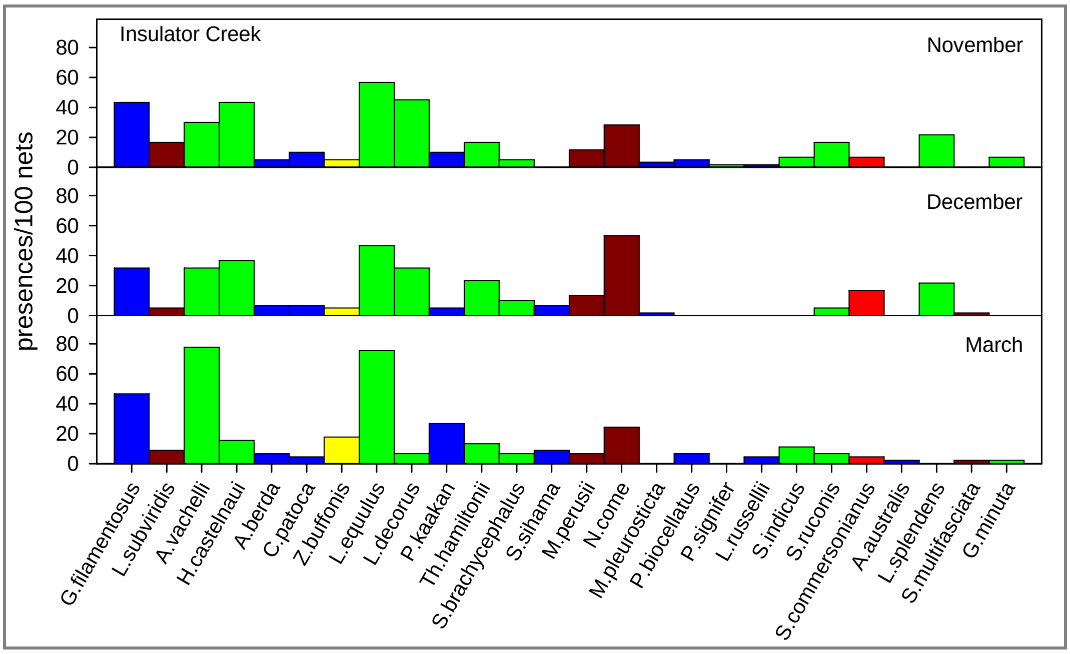


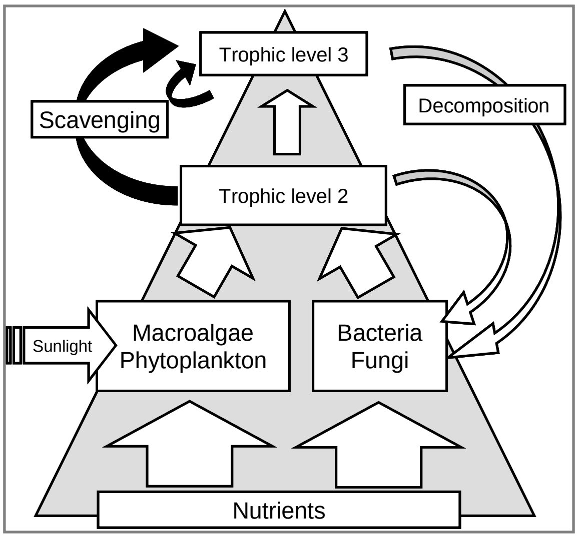
Figure 17: Species profiles for Insulator Creek.

3. Scavenging pressure

Scavenging is not a rare phenomenon. It occurs in and has been described in a variety of ecosystems, for example, terrestrial grasslands (Bestelmeyer and Wiens 2003), the deep sea (Smith and Baco 2003), and the intertidal zone (Rose and Polis 1998). A huge variety of animals scavenge, and as it would be rare for a hungry omnivore to forego a meal of fresh carrion (Whitehead and Reeves 2005). The diversity of taxa that scavenge means that within an ecosystem, scavenging is a process of the assemblage rather than of a single species.

By consuming carrion, scavengers steal biomass and energy from the microbes which would otherwise decompose the corpse (Putman 1983). Scavenging, therefore, can be considered to recycle nutrients within higher trophic levels (Figure 18). This consumption of carrion may supplement food supplies and lead to an increase in the biomass of scavengers and subsequently their predators, as well as generating alternative food web pathways.

Figure 18: Simplified food web showing the scavenging process recycling nutrients and energy to higher trophic levels, whereas energy falls to lower trophic levels when it is decomposed (J. Webley, PhD Thesis).



Because many animals are opportunistic scavengers, the potential for scavenging is driven by factors that also drive competition for food. More generally, the vigour of these trophic processes, which effectively shunt nutrition and biomass around food webs, are components of the vibrancy or health of the ecosystem. Generally, albeit not always, more active systems teaming with life would be considered healthier than those sparsely populated or lethargic.

The initial sampling completed in this project has indicated that fish assemblage structure alone will not be a sensitive indicator of ecosystem condition. Therefore, the fish assemblage data should be combined with measurements of key ecosystem processes, for example reproductive output or trophic transfer. Scavenging potential, which is a measure of competition for food, has been found to be correlated with water quality parameters of estuaries in southeast Queensland (Figure 19). While the specific assemblages of tropical estuaries are different to subtropical ones, factors underpinning scavenging potential, i.e. hunger and competition, should be fundamental to both types of systems. Scavenging potential will be assessed in our tropical systems in the next round of sampling, and its relationship to the naturalness index assessed.

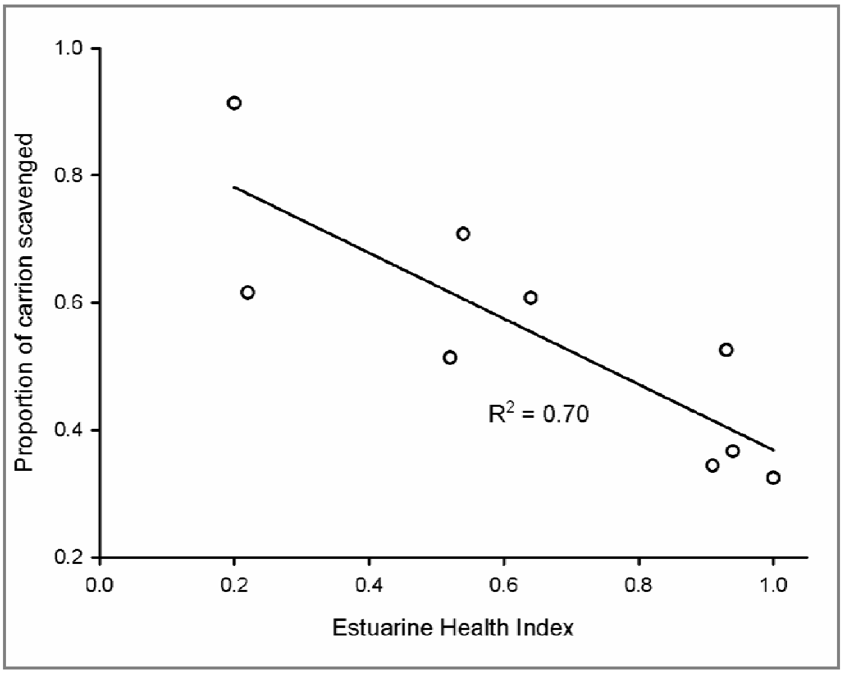


Figure 20: Mean proportion of carrion scavenged in nine different estuaries spanning a range of Ecosystem Health Index scores (based on a suite of water quality parameters) from 0.2 (poor water quality) to 1.0 (good water quality) (J. Webley, PhD Thesis).

4. Work to complete

Field data have been collected up to September 2008 and these samples are currently being sorted and added to the existing data set. This sampling will continue until March 2009 to provide a complete year sequence of data. The current periodicity of data collection has been reduced to every two months. This apperas adequate now the high recruitment season is passed and the patterns of change seen are clear and consistent, and will allow the team time to catch up on the outstanding laboratory work. Once the laboratory data set is complete most of the process level variables (e.g. trophic related variables) can be extracted directly.

Additional work is required to prepare and analyse stable isotope data. However, sample preparation for stable isotope analysis is up to date and should be finished shortly after the final field data are sorted. The only component requiring substantial additional work is the analysis of recruit persistence (involving collection of detailed size structure data). This component is well underway by a Masters student, Ashlee Johnston, who is working exclusively on this.

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