Relation between tidal wetland connectivity and estuarine fisheries in Queensland, Australia

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Abstract
Many commercially important fish species use estuarine wetlands such as mangroves, tidal flats and seagrass beds as nurseries or breeding grounds. The importance of estuarine habitat for fisheries has been studied often based on the outwelling hypotheses. The ecological importance of spatially connected habitats is well known for terrestrial environments. However, a few studies have applied the idea of spatial metrics, in particular, connectivity to marine environments. We examined the relationship between catch-per-unit-effort for commercially caught species in their dominant fisheries (trawl, line, net or pot fisheries) and estuarine geomorphic spatial metrics, extracted from geographic information systems in Queensland, Australia. We calculated spatial metric characteristics such as Euclidean distance, patch density and landscape connectivity for 273 estuaries and used inshore fish catch data from 23 species groups. Multiple regression analysis and nMDS plots show links between geomorphic coastal features and nearshore fisheries production for a number of species at a broad regional scale covering > 5000 kilometres of coastline. The relationship was best explained by connectivity indices for the estuarine habitat groups mangroves, saltmarsh and channels, suggesting the importance of connected tidal wetlands for fisheries. The findings could guide the construction of marine protected area networks of various sizes and spacing to maintain ecosystem services and avoid further reduction of connectivity by habitat fragmentation. The application of the same approach to analyses of different and finer spatial scales are required to enable catch information to be related to particular estuarine habitats and to allow for a full understanding of the importance of habitat connectivity for fisheries.

Introduction - Outwelling hypothesis from a fisheries perspective

Estuarine habitats such as mangroves, salt marsh, seagrass, channels, mud and sand flats are used by many commercially important fish species as nursery and breeding grounds, and for protection from predation (Blaber 2000, Beck *et al* 2001, Katherisan and Bingham 2001, Baker and Sheaves 2005). It is thought that food for juvenile fish and crustaceans is more abundant in estuaries than in other coastal habitats (Hutchings and Saenger 1987, Robertson and Blaber 1992, Laegdsgaard and Johnson 2001), for example through lateral trapping of nutrients within the vegetated areas and the primary production from algae and vascular plants (Wolanski *et al* 2001). It was once believed that mangrove and other coastal wetland primary production drove offshore fisheries production through the tidal exportation, i.e., 'outwelling', of nutrients (Odum and Heald 1972, Robertson and Blaber 1992, Lee 1995). More than thirty years ago Odum (1968) presented the idea of outwelling, following the hypotheses from Schelske and Odum (1962) that estuaries are highly productive, and that temperate salt marshes might export significant percentages of their organic production offshore to support secondary production (Teal 1962). The contribution of mangrove, salt marsh, benthic microalgae, seagrass and brackish-water vegetation to production in coastal waters has since been well accepted but poorly quantified, and there are no regional comparisons of sources and status of primary production in major bays and estuaries. Findings that one habitat type may provide less organic matter to the estuarine food chain than others (e.g. mangroves vs salt marsh) (Turner *et al* 2004) may not be valid at all regions and spatial scales (Connolly 2003) and spatial configuration. Thus, suggesting that a number of habitat types and their spatial connection are important drivers of nearshore fisheries.

Objectives

In this study we aim to define spatial metrics of the individual and combined estuarine habitats: seagrass, saltmarsh, mangroves, channels and mud- and sandflats; and relate them to CPUE values for different sections along the coast of Queensland. This will provide indicators for fisheries management to account for important habitat values and demonstrate the dependence between commercially important fish species and estuarine habitats.

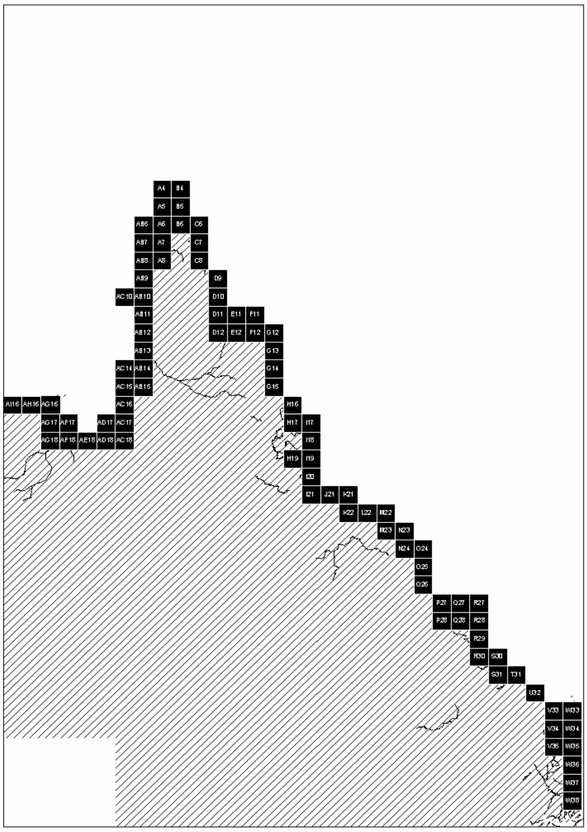
Theory - The connectivity factor

The connectivity of estuarine habitats seems to influence the productivity of nearshore consumers. There is broad interdependence among seagrass beds, marshes mangroves and adjacent coral reefs as underlined by a study from the Gazi Bay ecosystem (Kenya) using stable isotope analyses (Kitheka 1996, Marguillier *et al* 1997). The correlation of mangrove and salt marsh in estuaries also gives indications of a possible link between these habitats (correlation coefficient 0.79 for NSW (Saintilan, 2004) and 0.55 for Qld. (added by author)). Merriam (1984) first introduced the concept of landscape connectivity to emphasize the interaction between species attributes and landscape structure in determining movements of biota among habitat patches. Many species are dependent on the maintenance of connectivity between habitats to complete their lifecycles (Zeller 1998). Connectivity impacts on other ecological processes such as species distribution or population dynamics and can indicate the potential impact of connectivity on individuals, populations, and communities in heterogeneous landscapes. As pointed out by Moilanen and Nieminen (2002), connectivity (or its inverse, isolation) has long been recognized as a fundamental factor in determining the distribution of species (MacArthur and Wilson 1967, Fahrig and Merriam 1985), but application of the concept to marine ecology has been limited. So far, there are no studies that have created a connectivity index for tidal wetlands.

Material and Methods

Data on catch, effort (number of days and boats) and gross value of production for estuary dependent species or species groups were provided by the Queensland Department of Primary Industries and Fisheries (QDPI&F) Assessment and Monitoring Unit. This dataset is based on daily logbook records reported by commercial fishers providing details of their catch and effort, covering the years 1988-2004, and recorded in 30-nautical-mile grids (half-degree) for the entire coast of Queensland. A 1:100,000 coastal wetland vegetation map including information on mangrove communities were obtained from QDPI&F Assessment and Monitoring Unit. Data on channels, intertidal flats and sandflats for estuaries based on a 1:100,000 scale National Topographic Map series were taken from Geoscience Australia (Geoscience_Australia 2004). For the fish catch data, we selected 90 grids within a 30 km radius to the coastline (Figure 1), representing almost two third of Queensland’s total fish catch in 2004. Only numerically dominant species with relative constant and high market values, estuary dependents and occurrence throughout Queensland (based on Yerasley et al. (1999); pers. comments L. Williams, QDPI&F) were examined. Annual summaries of the fish catch data were calculated with latitudinal section, species or species group, fishery type and catch-per-unit-effort (CPUE, kg/day). We separated trawl and net, pot and line fisheries but combined CPUE for the later three, as these techniques can be considered passive and preliminary studies showed no significant differences when treated separately (Meynecke *et al* 2007). We compared the CPUE for all fisheries and for individual

Figure 1. Distribution of 90 selected fish catch grids with their fish catch record identification number provided by DPI&F.

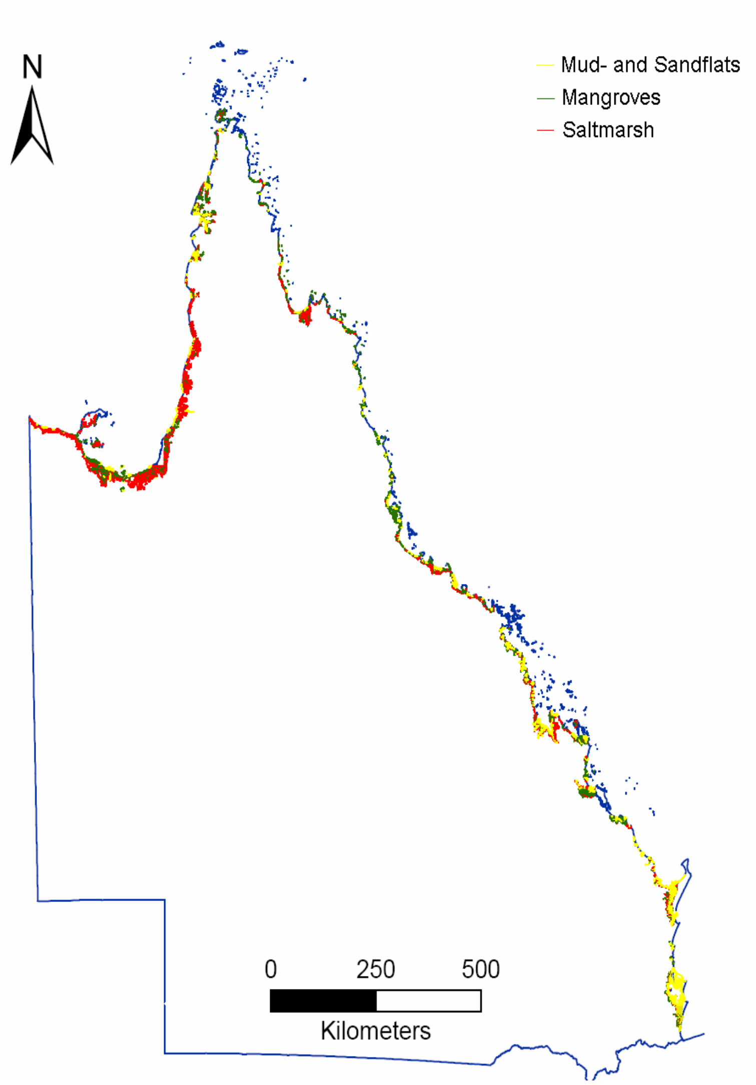


fisheries with derived connectivity parameters. Commonly available connectivity metrics such as patch density (PD), Euclidean nearest-neighbour distance (ENN), CONNECT (McGarigal *et al* 2002) and edge distance were selected to represent the degree of connectivity of estuarine habitat types for each section. Statistical analyses were carried out using the PRIMER 5.0 (Clarke and Ainsworth 1993) and SPSS 15.0 software packages. Correlation analyses were used to explore dependency and similarity among some of the variables. Non-metric multidimensional scaling nMDS was used to represent the similarity of estuaries on the basis of habitat connectivity (Conner *et al* 2002). The extent to which habitat variables explain the variability in fish catch and CPUE was determined using the BIO-ENV procedure (Clarke and Ainsworth 1993).

Results

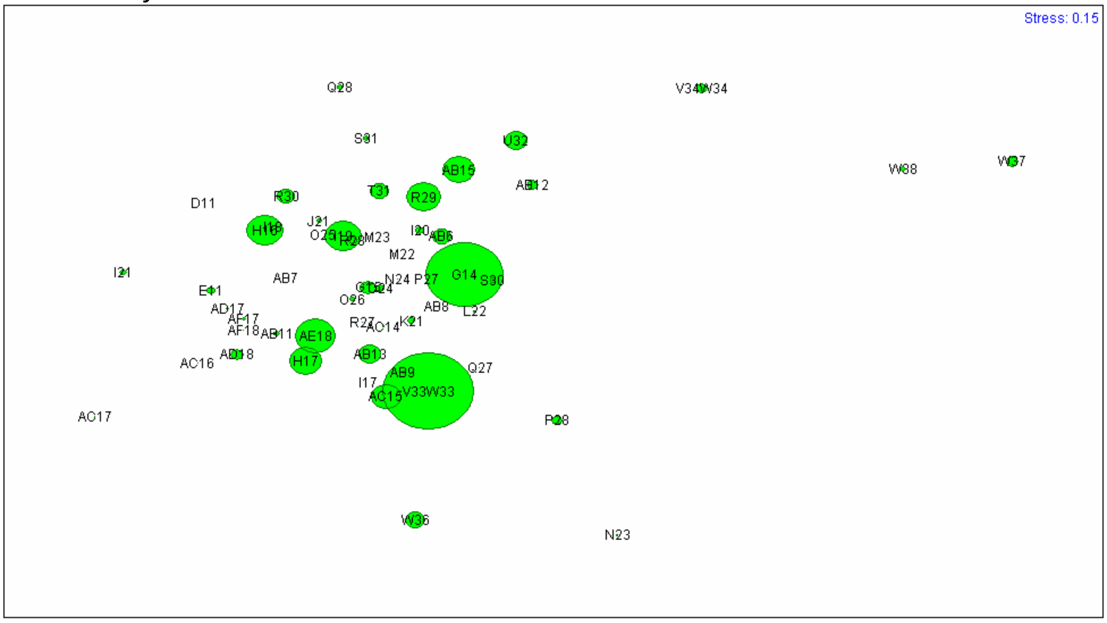
The habitat analyses showed large areas of wetlands in south-east Queensland and the Gulf of Carpentaria with saltpans dominating. Wetland connected edge to area ratio had core sections in the south-east (V35W35) and north of Queensland (G14) and the Gulf of Carpentaria (AG18, AD18); wetland CONNECT was highest in the south-east of Queensland, near Cairns and in some sections in the Gulf of Carpentaria (Figure 2). Outstanding sections in regard to CPUE were evident in the south-east of Queensland and northern sections around Cairns. nMDS plots with CPUE against wetland CONNECT showed that there was clear separation between sections of high CPUE and high wetland CONNECT values supporting the idea of habitat connectivity influencing overall high fish catch. Section along the east coast in particular S31, V35W35, W36, H19 and H17 had high CPUE with high connectivity (Figure 3) Results of BIO-ENV for the Gulf of Carpentaria showed the best Spearman correlation between CPUE (r = 0.58) for the parameters: (1) length of connected edge to area ratio, (2) number of estuaries, (3) seagrass patch density in this rank order. For the east coast of Queensland the 5 parameters wetland CONNECT, wetland patch density, flats number of patches, seagrass parameter:area ratio and mangrove number of patches provided the best correlation (r = 0.36). BIO-ENV results were based on Euclidean distance and no transformation of the entered parameters.

Figure 2. Tidal wetland habitat distribution with saltmarsh in red, mangroves in green and mud- and sandflats in yellow.



For both areas wetland connectivity metrics were the dominant explanatory factors of CPUE distribution. We found that barramundi and bugs CPUE from the east coast was best explained by the number of wetland patches, mangrove connectivity and length of connected habitat (r^2=0.34, P<0.01). The number of wetland habitat patches fitted best with prawns bay CPUE. Bream CPUE and whiting catch was best explained by the amount of wetland habitat. Dart CPUE, mullet catch, king prawns catch and tailor catch were best explained by wetland habitat patches and mangrove ENN, length of connected edge to area ratio and latitude (PCA scores 1 and 3). Prawns bait and blue swimmer showed the best correlation with scores from PC 1, 2 and 3. Mud crab CPUE from the Gulf of Carpentaria was best explained by wetland connectivity, number of saltmarsh patches and latitude. Saltmarsh parameter:area ratio and saltmarsh number of patches and latitude were most important to explain a linear fit for mullet CPUE, threadfin blue catch and threadfin king catch. Barramundi CPUE was best explained by the number of mangrove patches, mangrove CONNECT, wetland CONNECT, wetland parameter to area ratio and seagrass parameter to area ratio. All other groups showed no significant r^2 values for derived PCA scores.

Figure 3. None metric dimensional scaling with CPUE from 21 selected species being square root transformed Bray Curits with euclidean square. nMDS for 90 selected geographical areas (based on square root transformed catch data and Bray Curtis similarity) for Queensland. The value of the wetland connectivity area ratio is indicated by the size of circles.



The study supports the over-arching axiom in ecology that heterogeneity and connectivity of habitats at a range of scales plays a key role in determining the spatial distribution and abundance of animal species (MacArthur and Wilson 1967, Kotliar and Wiens 1990, McCoy and Bell 1991). More specifically, patch density and connectivity metrics explained a large and significant proportion of the variation in fish and penaeid prawn CPUE distribution. This further indicates that the role of estuarine habitats is dependent of their size and configuration (Guest and Connolly 2006). Analyses from previous studies also showed a strong dependency by species groups to estuarine wetland habitats (mud- and sandflats, mangroves, channels and saltmarsh) with the connectivity and wetland metrics being the dominant explanatory factors (Meynecke *et al* 2007).

Take home message

We propose that continuously connected landscapes have the most important value per unit area for most of estuarine dependent and commercially important fish species. The importance of landscape connectivity of estuarine habitats may be explained by the high mobility (active and passive) of organisms in the water column, thereby facilitating transport over broad spatial scales. Urbanization impacts on coastal wetlands through hydrology, geomorphology and direct habitat alteration and causes isolated habitat patches which increase the risk of predation and of physiological costs (e.g. extensive migration). Along with loss and fragmentation of habitats, human modifications to the surrounding landscape (e.g. through clearing in the catchment) may significantly influence the connectivity of estuarine habitats

(Haynes and Cronin 2004) with the consequence of loss of flow, structural diversity, channel narrowing, depth reduction and ultimately less fish species (Jansson *et al* 2007). Low-connectivity scenarios may not be able to support viable populations of certain species over long periods of time (Dethier *et al* 2003). It is therefore desirable to quantify connectivity at different spatial scales and use these measurements as a basis for decision-making. The advantage of spatial pattern indices is that they can be used to quickly characterize connectivity for large areas.

Acknowledgement
The authors like to thank Griffith University and the Commonwealth Government for funding the research. DPI&F for provision of data on fisheries and habitat and Dr Jan Warnken for assistance in the GIS facility and Dr Malcolm Dunning, Lew Williams, Leonard Olyott, Karen Danaher (DPI&F) and Michael Arthur (Griffith University) for help and useful discussions during this study.

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