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Spatio-temporal modelling of prawns in Albatross Bay, Karumba and Mornington Island

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ABSTRACT

The seasonal life-history patterns of penaeid prawns are complex and there are distinct differences between species. Better knowledge and understanding of offshore migration to the fishing grounds of penaeid prawns is particularly important for the operation and management of the Northern Prawn Fishery, Australia. Knowledge of the location of prawns during the critical spawning period of the year is important, especially since recent work suggests that inshore areas are critical for effective spawning. This paper explores factors, such as rainfall, water depth and season, impacting prawn migratory patterns, and models the spatial and temporal distribution of three commercially valuable species of prawns (*Penaeus merguiensis*, *Penaeus semisulcatus* and *Penaeus esculentus*) in Albatross Bay, Karumba and Mornington Island in the Northern Prawn Fishery using modern statistical methodology. The methodology allows for flexible functional relationships between variables, including univariate smooth terms and smooth terms for interactions between covariates: a major advancement on the methodology used in previous analyses of spatial distribution of prawns in the Gulf of Carpentaria. The models interpolate well, but expose the problems associated with extrapolation beyond the data. The results suggest that there are spawners in the important inshore waters during the critical spawning period of the year, although there is no strong evidence for major congregations of prawns in these important inshore regions compared to more offshore regions. Rainfall was significant in many of the models, particularly those describing the distribution of *Penaeus merguiensis*. Increased rainfall mostly had a positive effect on prawn catch rates, possibly by stimulating prawns to move out of shallow coastal areas into the fishing area. However, in some cases, high levels of rainfall had a negative effect which may be due to storms associated with the heavy rainfall decreasing the effectiveness of the fishing fleet. The analyses showed no signs of major inshore migrations associated with spawning, but there were certainly some spawners close inshore at the critical spawning period.

1. Introduction

The life-history patterns of penaeid prawns are complex and there are marked differences between species (Dall et al., 1990). In many penaeid prawn fisheries throughout the world, including the Northern Prawn Fishery (NPF), Australia, all the commercially important species have a life cycle where the adults spawn in offshore waters, larvae and postlarvae move inshore and, after several months in estuarine or coastal nursery areas, the juveniles and subadults move offshore again. Two aspects of the spatio-temporal distribution associated with this life cycle are particularly important for the operation and management of the NPF—the offshore migrations to the fishing grounds and the location and timing of the reproducing adults.

The timing and extent of migration of the young adult prawns from the inshore nursery areas to the offshore fishing grounds largely determines when the prawns are available for capture by the fishing fleet and the size of the catch. For banana prawns, *Penaeus merguiensis*, in some regions of the NPF, it has been shown that migration of the prawns out of the nursery areas is in part related to the amount of rainfall that falls in the coastal areas (Vance et al., 1985, 1998; Staples and Vance, 1986). Increased offshore commercial catches of adults is often associated with high rainfall. However, it is not clear if the increased commercial catch is due to an increase

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in the population size resulting from increased production, or if it is simply an increase in catchability as the whole population simply moves further offshore into the fishing grounds. If the latter scenario is the case, then the spawning stocks are in much greater danger of being over-fished in high catch years.

Knowledge of the size and location of the spawning stock for each species of prawn is also important for the management of the fishery. Previous work has suggested that typically, tropical penaeids have two spawning periods each year (see Pauly et al., 1984; Garcia, 1985, 1988; Dall et al., 1990; Staples and Rothlisberg, 1990; Crocos and van der Velde, 1995). However, other work does not always bear this out (see Rothlisberg et al., 1987; Crocos, 1987a, 1990), suggesting variability exists between years and regions. There is also clearly variability between species. In the western Gulf of Carpentaria, brown tiger prawns (*Penaeus esculentus*) were found to spawn for much of the year whereas grooved tiger prawns (*P. semisulcatus*) had a much more limited spawning period (Crocos, 1987b). Despite these temporal patterns of spawning it has been suggested that spawning during only a relatively short period of the year results in most of the recruits for the next year's commercial catch in the NPF (Rothlisberg et al., 1985).

In more recent times, a series of studies modelling water currents and the advection of larvae and laboratory studies on the behaviour of postlarvae have suggested that the spawning that contributes most to subsequent generations is quite limited in space, particularly to the inshore areas of the fishery (Condie et al., 1999[1]). This has given rise to the concept of the "effective spawning" population of the prawn fishery (Crocos and van der Velde, 1995). This possibility is supported by the research of Dredge (1985) who found that on the east coast of Australia a small proportion of the adult population of *P. merguiensis* returned from offshore waters and spawned in estuarine areas. This behaviour has also been suggested by Neal (1975) for the white shrimp (*P. setiferus*) fishery in the Gulf of Mexico. In the NPF, *P. semisulcatus* disperse to deep water offshore from the fishing grounds in the first half of the year and then return onshore to the fishing grounds after July each year. It is not clear what proportion of these prawns move into close inshore waters.

There can be marked variability within and between years in abundance and distribution of penaeid prawns in the NPF. Crocos and van der Velde (1995) show this for adult female *P. semisulcatus* in Albatross Bay, Gulf of Carpentaria, Australia, while Somers et al. (1987) examine the abundance and distribution of *P. semisulcatus* and *P. esculentus* in only the north-western Gulf of Carpentaria. With long-term declining commercial catches of *P. semisulcatus*, *P. esculentus* and *P. merguiensis* in the Gulf of Carpentaria, there is a need to model the spatial and temporal distribution of abundance or the migratory patterns of these species, and to determine the factors driving these patterns.

Most information on the spatial and temporal distribution of prawns on and near commercial fishing grounds comes from commercial catch data. However, there are often difficulties in interpreting this data, particularly due to variation in fishing effort. Scientific surveys are a more reliable way of collecting accurate data but the high financial cost means that long-term datasets are not often collected. However, the benefits of having access to long-term survey data can be seen from the work of Craig et al. (2005) who were able to assess the spatial distribution of brown shrimp (*Farfantepenaeus aztecus*) in the Gulf of Mexico in relation to prawn density and environmental variation using bottom trawl survey data spanning 18 years. Also in the Gulf of Mexico, Li and Clarke (2005) used 14 years of trawl survey data to show a significant relationship between sea surface temperature and catch rates of brown shrimp. Haas et al. (2001) using commercial catch data were not able to detect this relationship which suggests that the survey data gave a more accurate indication of population abundance than the commercial catch data.

This paper explores factors impacting migratory patterns and models these patterns for *P. semisulcatus*, *P. esculentus* and *P. merguiensis* in Albatross Bay, Karumba and around Mornington Island in the Gulf of Carpentaria. This is done using a combination of historical survey and recent survey data. Modern statistical methodology such as generalized additive models (GAMs) is used to analyse data and make predictions.

2. Data

The data analysed in this paper come from historical and recent surveys. In the Albatross Bay region historical data was collected monthly (at least for the first 3 years) between March 1986 and March 1992 (for more details see Crocos and van der Velde, 1995). For Karumba the historical survey data was collected approximately monthly between August 1977 and August 1978 (for more details see Crocos and Kerr, 1983). No historical data is available for the Mornington Island region.

For Albatross Bay more recent survey data was collected between January 2003 and January 2005 four times a year, approximately in the months January, March, August and October. For the Karumba region the recent survey data was collected during the same period as that for the recent Albatross Bay survey, except that no sampling took place during October 2003 and 2004. Finally, for the Mornington Island region sampling took place between August 2002 and January 2005, approximately in the months January, March and August.[2]

A clearer picture of when sampling took place can be acquired from the prediction maps in Section 4, since prediction maps are generated only for those months for which samples were collected. The only exception is the prediction maps for March 1986 in Albatross Bay. These maps are not generated since they are based on only 1 month of observation for the fishing year 1985–1986 (see Section 4.1.1 for definition of fishing year).

3. Statistical methodology

The variables of interest are the total catch of the three prawn species for each survey trawl. Consequently generalized additive models (GAMs) are used to model the total catch variables. Given that counts of prawns are being modelled, the Poisson and negative binomial distributions can be employed to model the total catch. In this paper only the Poisson distribution is considered because preliminary work with the negative binomial led to anomalous results.

The Poisson distributed Y_i random variable with mean μ_i has the following probability distribution:

$$P(Y_i = y_i) = \frac{\mu_i^{y_i}\, e^{-\mu_i}}{y_i!},$$

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[1] See also Vance, D.J. and Pendrey, R.C., 2001. The definition of effective spawning stocks of commercial tiger prawns in the Northern Prawn Fishery and king prawns in the eastern king prawn fishery—behaviour of postlarval prawns. FRDC Report No. 97/108. The report can be accessed at http://www.frdc.com.au.

[2] For more details on methods used during the surveys see Dichmont, C.M., Vance, D., Burridge, C., Pendrey, B., Deng, A., Ye, Y. and Lonegran, N., 2003, Designing, implementing and assessing an integrated monitoring program for the NPF, Final Report for FRDC Project 2002/101, and Dichmont, C.M., Vance, D.J., Burridge, C.Y., Toscas, P.J., Zhou, S., Pendrey, R.C., van der Velde, T.D., Taranto, T., and Donovan, A., 2006, Is the inshore area a spatial refuge for commercial prawns in the NPF? At-sea research to develop a new method of evaluating catch rates of banana and tiger prawns, Final Report for FRDC Project 2002/014. Both reports can be accessed at http://www.frdc.com.au.