Development of a Seagrass - Fish Habitat Model: Estimating commercial catch using regression, effort and seagrass area.

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Abstract Seagrass plays a major role in supporting the processes and function of the marine environment and is a key fisheries habitat, which provides nursery, feeding and breeding areas for fish and crustaceans. Seagrass beds also stabilise the seabed, trap sediments, reduce coastal erosion and provide the basis for the food chain through photosynthesis. This paper forms a part of a PhD project - the Development of a Seagrass Fish Habitat model - the aim of which is to construct a spatial and temporal model which quantifies the effects of seagrass habitat loss upon fisheries production (in biomass and dollars) in South Australia. Qualitative assessment of the relationship between seagrass and fisheries production supports the assumption that degradation in seagrass areas will detrimentally impact on the production of some species which are known to have a link with seagrass. This paper describes a linear relationship between the two explanatory variables, effort (in boat days) and seagrass area, and the commercial catch of some economically important species in South Australia.

1. INTRODUCTION

The relationship between seagrass and the fauna it supports is the subject of considerable research and the literature is replete with information on species abundance and composition in and adjacent to seagrass beds [Connolly, 1994; Connolly et al. 1999; Ferrell and Bell, 1991; Heck and Orth, 1980; Jenkins and Wheatley, 1998; Jenkins et al. 1993a; Kikuchi, 1980]. It has been shown that the richness and abundance of marine fauna in seagrass beds is greater than that in unvegetated areas [Bell & Pollard 1989; Connolly 1994; Edgar et al. 1994; Jenkins et al. 1997] and that this diversity declines following seagrass destruction or dieback [Edgar et al. 1993; Jenkins et al. 1993b]. As well as providing habitat for fisheries, seagrass meadows play an important role in the processes and resources of near-shore ecosystems. They are areas of high biological productivity, they reduce water movement and thereby prevent erosion, and they trap sediments and organic matter, which provide food for bottom foraging organisms. Primary productivity (the conversion of sunlight into food, via photosynthesis) of seagrass contributes significantly to the productivity of the marine environment. In Spencer Gulf, in South Australia, an area rich in seagrass meadows, Smith & Veeh [1989] calculated total fisheries yield to be 0.02% of estimated net primary production (production of organic carbon by seagrass and plankton through photosynthesis per unit area per unit time).

If a quantitative relationship can be established between seagrass and fisheries production through the use of mathematical modelling, the ability to estimate the financial contribution of seagrass to this industry will be greatly enhanced. The primary aim of this study is to construct a cellular or unit model, which describes the relationship between the seagrass area and the commercial catch in each unit area. The unit cell is based on the GARFIS fishing blocks (see Figure 1) which was established in 1983 to aid collection and storage of commercial fishing data in South Australia.

2. BACKGROUND

Regression analysis provides a method by which correlations between seagrass area and commercial catch (in each fishing block) can be calculated. The multiple linear regression model has the basic form:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \varepsilon \quad (1)$$

where Y is the dependent response variable, and the X_i s are the independent explanatory variables. The β_i s are regression coefficients and ε is an error term, assumed to be normally distributed.

Scott et al. [1999b] establish a good correlation between two explanatory variables (effort and seagrass area) and the response variable (commercial catch) using multiple linear regression Their data was extracted from the GARFIS database and included catch and effort figures from 58 fishing blocks, over a period of fifteen years for eleven of the most highly prized species. Effort is given in terms of the number of boat days spent in pursuit of the corresponding catch, which is in kilograms of live weight. Information on seagrass and reef area in South Australia was supplied by Edyvane, [1999]. Non-targeted catch and non-targeted effort were not included and the total sum of the seagrass and reef area were combined to form the seagrass variable.

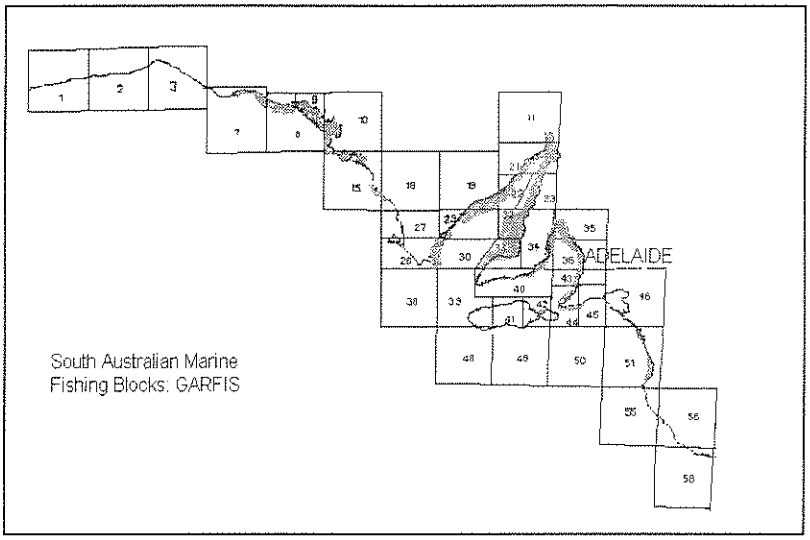

Figure 1. Diagram showing the South Australian fishing zones. The shading indicates the approximate distribution of seagrass. (Seagrass area data comes from Edyvane, 1999).

The regression models, which also included an effort squared variable, were assessed with comparisons made between resulting R^2 values. The significance of each predictor was tested using partial F-tests [Berenson et al. 1993]. This test determines whether the addition of the $(k+1)th$ variable improves the model, given the inclusion of the previous k variables. For example; given the linear model containing the variable 'effort', does the addition of the variable 'seagrass' (or the addition of the variable 'effort squared') improve the model significantly? The F-test involves the comparison of the ratio of the sums of squares due to the new variable given the previous variable(s), over the mean sum of squares, to a value from the t-distribution, given the appropriate degrees of freedom.

Scott et al. [1999a] developed a seagrass residency index (SRI) which enables identification of those species that display a close association in terms of 'residency time' with seagrass beds. Species with high residency indices, in the context of the model development, are indicated in Table 1, with their corresponding index. It was anticipated that species with high SRIs (greater than 0.7) would have a significant contribution from the seagrass variable contained in the model, and this proved to be the case (see Table 2).

The models obtained from these analyses are given in Table 2 with the corresponding coefficients of determination. The constant, β_0, was zero for all species, and the significance for all variables is at the 0.05 level as determined by partial F-tests. The presence of effort squared in the model in conjunction with a negative coefficient, could possibly indicate over fishing since a quadratic model, when the coefficient of the squared term is negative, has a maximum point beyond which further effort would not yield greater catch.

Species: Common Name	Taxonomic Name	*SRI*
Southern Sea Garfish	Hyporhamphus melanochir (Valenciennes)	0.98
King George Whiting	Sillaginodes punctata (Cuvier)	0.96
Tommy Ruff	Arripis georgiana (Valenciennes)	0.95
Southern Calamary	Sepioteuthis australis (Quoy & Gaimard)	0.79
Blue Swimmer Crabs	Portunus pelagicus (Linnaeus)	(0.74)*estimate
Yellowfin Whiting	Sillago schomburgkii (Peters)	0.64
Australian Salmon	Arripis truttacea (Cuvier)	0.56
Snapper	Pagrus auratus (Forster)	0.37
Sand Flathead	Platycephalus bassensis (Cuvier)	(0.26)*estimate
Mulloway	Argyrosomus hololepidotus (Lacepede)	0.0
Pilchard	Sardinops sagax (Steindachner)	0.0

Table 1. List of species included in the analysis. *Information for Blue crab and sand flathead was not available to calculate their SRI, and an experts' estimate has been given in place.

Species	SRI	Best Estimated Model	R^2
Southern Sea Garfish	0.98	$c = 136e + 0.007e^2 + 69s + \varepsilon$	0.980
King George Whiting	0.96	$c = 18e - 0.0004e^2 + 205s + \varepsilon$	0.930
Tommy Ruff	0.95	$c = 935e - 0.506e^2 + 81s + \varepsilon$	0.785
Southern Calamary	0.79	$c = 47e - 0.002e^2 + 82s + \varepsilon$	0.843
Blue Swimmer Crabs	(0.74)	$c = 140e + 187s + \varepsilon$	0.882
Yellowfin Whiting	0.64	$c = 370e - 0.177e^2 + 43s + \varepsilon$	0.720
Australian Salmon	0.56	*N/A*	*N/A*
Snapper	0.37	$c = 76e + 0.001e^2 + \varepsilon$	0.958
Sand Flathead	(0.26)	$c = -123e + 12e^2 + \varepsilon$	0.957
Mulloway	0.0	$c = 42e + 0.008e^2 + \varepsilon$	0.990
Pilchard	0.0	$c = 287e + 4.8e^2 + \varepsilon$	0.681

Table 2. The resultant linear regression models from Scott et al. [1999b] giving the values of the regression coefficients, β_1, β_2, β_3 and the coefficients of determination, R^2.

3. METHOD

The results obtained in the study by Scott et al. [1999b] prompted further investigation and refinement of the model. We have included non-targeted catch and non-targeted effort and removed the reef area contribution to the seagrass variable. Days on which the effort is greater than zero and the catch is zero are not recorded, which implies that the actual effort is not really known since unsuccessful days are not counted. However the fishers do record non-targeted catch and non-targeted effort is calculated from the following relationship [Fowler and McGarvey, 1997]:

$$\frac{\text{non-targeted effort}}{\text{targeted effort}} = \frac{\text{non-targeted catch}}{\text{targeted catch}}. \qquad (2)$$

The catch and effort is summed over 15 years of data as before and the seagrass area is assumed to be constant. We assume independence between the two variables effort and seagrass area and support this assumption by examining the statistical correlations (r) between the two variables. The results of these correlations is given in Table 3, and although the r^2 is above 0.5 for three species, (garfish, crab, snapper), it is possible that other factors are influencing effort. Some of these could be the method of capture, the depth of water, and the closeness to shore, all of which might have positive or negative correlations to seagrass. There was no significant contribution to the model by the seagrass variable (see Table 2) for those species which have little association with seagrass throughout their life-history [Scott et al. 1999a], and all species with an SRI below 0.7 have been excluded from the present analysis leaving a total of five species remaining in the study, which are given in Table 4.

The models developed for all species in the study by Scott et al. [1999b] included effort as a significant predictor in all cases, and this is assumed for the revised regression models. The regression coefficients were calculated using the statistical software package SPSS®. The significance of the second variable (seagrass) was determined using the partial F-test. The model for only one species includes effort squared, however, the coefficient is positive, so over fishing is not indicated. The constants in the regression models were found to be zero in all cases and the significance of the correlation is at the 0.005 level. The results of the regression analysis are given in Table 4.

Species	SRI	Correlation between seagrass and effort r^2
Southern Sea Garfish	0.98	0.629
King George Whiting	0.96	0.173
Tommy Ruff	0.95	0.315
Southern Calamary	0.79	0.132
Blue Swimmer Crabs	(0.74)	0.576
Yellowfin Whiting	0.64	0.344
Australian Salmon	0.56	0.007
Snapper	0.37	0.665
Mulloway	0.0	0.005
Pilchard	0.0	0.058

Table 3. The correlation between seagrass and effort over all zones for all of the species under investigation in the project except for sand flathead, which is targeted primarily in only two zones, 35 and 36.

Species	Best Estimated Model	Best Model Adjusted R^2	Effort only model Adjusted R^2	% improvement
Southern Sea Garfish	$c = 69e + 0.007e^2 + 89s + \varepsilon$	0.979	0.952	2.7%
King George Whiting	$c = 18e + 287s + \varepsilon$	0.942	0.867	8.6%
Tommy Ruff	$c = 460e + 286s + \varepsilon$	0.799	0.689	15.9%
Southern Calamary	$c = 42e + 147s + \varepsilon$	0.863	0.807	6.9%
Blue Swimmer Crabs	$c = 120e + 349s + \varepsilon$	0.898	0.859	4.5%

Table 4. The models which were determined for the five species with high SRI values (> 0.70) with their corresponding coefficients of determination (R^2). The last two columns compares the regression model with the contribution from the seagrass variable to that without.

4. CONCLUSIONS

The refinement of the data did not significantly alter the nature of the regression models in comparison to the models constructed by Scott et al. [1999b]; in fact, the order of magnitude of the regression coefficients and the R^2 values are comparable. The removal of the reef area from the data did not appear to alter the significance of the contribution of 'seagrass', whose contribution remained significant. The refinement of the catch and effort data to include non-targeted values appeared to have the effect of eliminating the effort squared variable from most of the models. In the garfish model, effort squared contributed significantly to the prediction of catch whereas the addition of seagrass resulted in only a marginal increase in the R^2 value (addition of s improved the value from 0.977 to 0.979) and this is reflected in the failure of the partial F-test when seagrass is added as a predictor. However, there is a 64% correlation between area of seagrass and total catch of garfish (targeted + non-targeted catch), and this variable (seagrass) becomes significant when added to a model which is quadratic in effort. A scatter graph (Figure 3) shows the quadratic nature of the data. The final model for Garfish is illustrated in Figure 4.

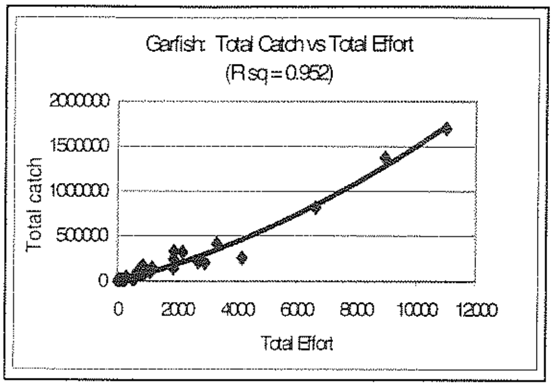

Figure 3. A scatter diagram of the catch and effort for garfish, including the polynomial model in effort.

An important aspect of this investigation is the relationship between effort and seagrass. The motivation for fishers selecting a specific block to target a particular species could involve very complicated issues. The blocks covering the two gulfs are well represented by seagrass coverage, and are both highly targeted commercial

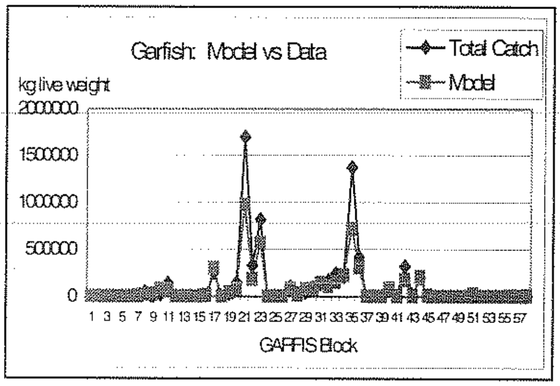

Figure 4. The graphical representation of the real versus the predicted catch for garfish.

fishing areas which could be due to the proximity to Adelaide and other major urban centres. It also must be noted that although a block might contain significant seagrass area, there is still a considerable expanse of bare sand in that same block.

Figure 4 illustrates the exceptional fit of these regression models. The two peaks where the catch exceeds the predicted catch are in zones 21 and 35, both of which contain considerable areas of seagrass.

5. APPLICATION

These regression models will be incorporated into the general seagrass fish-habitat spatial and temporal model. This will consist of cellular units which will estimate the fish biomass, in terms of imports and exports, in that cell. Effort will be given in terms of its most important predictors, which have not yet been identified, but will certainly include a distance from Adelaide or market price component. In essence, we are using statistical methods to determine where there are dependencies of one variable on others. eg. catch is dependent on effort, effort squared and seagrass for garfish, so in the spatial model catch will be assumed to be a function of effort, effort squared and seagrass as in equation (3).

$$c_x = f_x(e, e^2, s) \tag{3}$$

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