CHAPTER TWO

Guidelines for the Protection and Provision of Shorebird Feeding Habitat in Southern East Coast Estuaries

Summary: The important attributes of shorebird feeding habitat in estuaries that were identified in Chapter 1, were quantified to provide minimum target values to aim for in preservation and provision of habitat. These values are mean guide values for when changes are occurring to shorebird habitat, and are not for assessing the importance of existing sites, which will show natural variation (dealt with in Chapter 3). Symmetrical regression lines were used to predict mean values of the attributes used by arbitrarily defined low and high numbers of birds. These values were then assigned to Suitable and High Suitability classes in Habitat Suitability Models, summarised below, for use on habitat with the corresponding numbers of shorebirds:

Shorebird Species	Habitat Attribute	Minimum for Suitable Habitat*	Minimum for High Suitability*
Bar-tailed Godwit	Area of Flat Proportion of Dry Ground #	10.5ha or more 61% or less	21ha or more 16% or less @
Whimbrel	Surrounding Mangrove	28% or more	57% or more
Eastern Curlew	Total Habitat Area $	19ha or more	52ha or more
Greenshank	Proportion of Wet Ground # Surrounding Mangrove	44% or more 84% or more	67% or more 98% or more
Tattler	Adjoining Mangrove	32% or more	55% or more
Pacific Golden Plover	Area of Surrounding Habitat $	45ha or more	64ha or more @
Species number (3 or more)	Surrounding Mangrove Perimeter Length # Area of Surrounding Habitat $	61% or more 1 990 m or more 26ha or more	* Mean of guide range # at low tide $ within 1km @ not supported by testing

The models were then tested by comparing the regression lines with those of an independent sample of intertidal flats on different estuaries. Of the 11 primary relationships used, 9 also existed in the testing sample (82%). Other guide values were derived from correlated attributes, the range of values measured in the sample, observed disturbance distances, and measured elevation levels. The guide values provide guidelines for environmental impact assessment, estuary and reserve management, and construction and enhancement of shorebird feeding habitat.

Chapter 2

Guidelines for the Protection and Provision of Shorebird Feeding Habitat in Southern East Coast Estuaries

Introduction

This chapter contains habitat models (Farmer *et al.* 1982; Marcot 1986) developed from the research in Chapter 1. The purpose of these models is to provide estuary and wildlife managers with guidelines for the conservation and provision of intertidal feeding habitat for migratory shorebirds in estuaries, in the form of target values (Sutor 1990). Chapter 1 addressed the question: What attributes of shorebird feeding habitat need to be conserved or provided? This chapter addresses the question: How much of each attribute needs to be conserved or provided?

It relates the attributes of feeding habitat to prescribed numbers of the six common shorebird species in the study. These numbers are based on abundance during the study and conservation status defined by Smith (1991). The resulting models provide a selection of target values to aim for in the management of habitat for each shorebird species. These target values, or guide values, are based on means and are not for assessing shorebird use of existing flats, which will show natural variation (see Chapter 3).

The use of numerical criteria has long been a part of resource management. For example, in 1884 the New South Wales government required a permit for the destruction of trees over 12 inches (30.5cm) diameter at 4 feet (1.2m) above ground, in an effort to reduce the gross wastage of millable timber through felling and burning or ringbarking by our pioneers (Webb 1968). Some guide values predate scientific quantification. An estuarine example is the minimum criterion for tidal amplitude in canal estates of 0.3m (one foot), originally just a general guide based on best judgement, which has become a specific legal condition through the "passage of time" (Dunstan 1990). Though based on quantitative analysis of ecological data, the guide values in this chapter are still essentially subjective and are offered in the spirit of guidelines (see *General Discussion*). They are for the management of individual tidal flats, because estuarine land-use commonly affects

Plate 3 *Sandon River estuary, Yuraygir National Park, northern New South Wales.*

specific sites. This approach is appropriate even for the management of diffuse impacts, because the total habitat of an estuary is made up of individual flats.

The *Results and Discussion* section develops and explains guide values for each common species, and there are also summary tables to allow a considered overall management strategy. Other guide values for disturbance management and construction of shorebird feeding habitat (Davidson 1984) are also developed. Construction of feeding habitat is sometimes offered as a mitigation of intertidal habitat loss, for example during the Federal Airport Authority's impact assessment of the Third Runway in Botany Bay (Adam 1993). Despite doubts about its ecological or logical validity, and its ability to stop net loss, impact mitigation by habitat construction is often politically expedient. If done well on otherwise degraded sites, it has a place in conservation management, as does legitimate habitat restoration. The *General Discussion* then deals with each attribute of habitat in the context of shorebird conservation, and suggests applications for the guide values.

Methods

General Method

Once the important attributes of habitat were identified (Chapter 1), the measured values of these were used to develop two types of habitat suitability models (Wissel 1992). Both types relate values of the attributes to corresponding numbers of birds, using three threshhold numbers to form classes (Table 2.1).

"Mean Models"

The type of model reported in this chapter uses the *average values* of the attributes for each bird class. The classes are assigned "low habitat suitability" (eg. no birds), "suitable habitat" (some birds), and "very high habitat suitability" (many birds) (USFWS 1980; SWC 1987). These models give average guide or target values to aim for in the management of habitat, and are called here "Habitat Suitability Mean Models" to differentiate them from the models in Chapter 3.

"Range Models"

The other type of model (Chapter 3) uses the *whole range* of each attribute in each bird number class, and the classes are assigned "low", "high" and "very high conservation value". These models can be used to predict the likely use of other flats by shorebirds, and therefore help predict their conservation value. They are for site assessment purposes, and the term "Habitat Suitability Range Models" has been coined for them.

Testing the Models

All models were then tested using an independent data set of 43 intertidal flats from 13 different New South Wales estuaries. Slope and elevation of the trend (regression) lines were compared to assess the reliability of the mean models.

Other Guidelines

Disturbance distances, intertidal heights and the ranges of the attributes of natural tidal flats are also quantified for management and habitat creation or restoration. More detailed descriptions of the methods follow; Chapter 1 Discussion: *Limitations* explains some important considerations to bear in mind when using the models.

Selection of Relevant Habitat Variables

Only variables significant at the adjusted significance levels were used as main guide values (see Chapter 1: Methods: *Significance Levels*). Supplementary guide values are given for those which correlated with the main variable, and/or were significant at $P <= 0.05$. These are indicated in the text and tables. The first main variable selected for a model was the one with the highest level of significance and explained variance when regressed singly against shorebird number. Selection of subsequent main variables for a model was based on this criterion and lack of cross-correlation at $P <= 0.05$ with those chosen before.

Modelling Analysis

The models provide single "average" target values to aim for in conservation management, restoration and construction of habitat, so they employed a measure of central tendancy. They needed to consider each attribute individually, so were constructed as a table of discrete variables (for example see Table 2.2). The arbitrary "habitat suitability" classes were based on the range and frequency distribution of bird numbers on the main sample of 63 intertidal flats, social behaviour of the species, and conservation priority of the species (see Tables 2.1, 3.8). The classes between species. For example, a flat with 5 Whimbrel, a species which has relatively low population density and solitary feeding behaviour (Lane 1987), was assigned "very high habitat suitability for Whimbrel", whereas a flat with only 5 Bar-tailed Godwit, which are much more abundant and tend to flock on feeding grounds, was assigned "low habitat suitability for Bar-tailed Godwit".

Predicting Habitat from Bird Use

Regression was used to predict mean values of the variables for each threshhold shorebird number (habitat suitability class) (Brennan *et al.* 1986). Because the regression relationship was being used "backwards", Geometric Mean Regression (Ricker 1984; Krebs 1989) was used, which takes the form:

$$y = \left(\bar{y} - \left(\frac{b}{r}\right)\bar{x}\right) + \frac{b}{r}\,x$$

where y = response, x = predictor, $\bar{y}$, $\bar{x}$ = means, r = correlation co-efficient, b = regression coefficient.

G.M.R. is symmetrical, that is, the slope of y on x is identical to the slope of x on y. It is also more robust to measurement errors in both axes, high variability in both axes, and departures from normality; and regression line significance, error and confidence intervals are the same as ordinary regression. Linear regression was used because the generalisation of a straight line was more appropriate than a curve for the application (and variances) of the models (Smith & Conners 1986).

Zones of Confidence and Ranges of Target Values

A single, dogmatic target value was not adopted, but rather a limited range of values to aim for, based on the regression line's 95% confidence interval. For each guide value, the mean value of the line (central trend), which is actually a mean of a mean range, is given together with + or - values for the 95% confidence interval (Fig. 2.1). Thus a "guide zone" is provided rather than a "guideline". This was considered more appropriate for a variable ecosystem and the imprecise art of estuary management. The lower limit of the range, arbitrarily based on the lower 95% confidence interval, is used and interpretted as the minimum acceptable value which should be aimed for in management of that attribute of shorebird habitat.

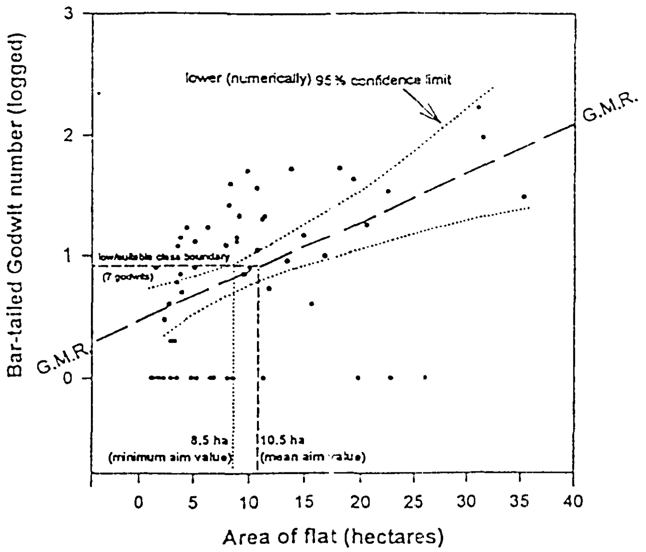
Two guide zones are given in each species model: the (lower) threshold of both the "suitable habitat" class and the "very high habitat suitablility" class. Target values for the "suitable habitat" class imply that levels of the attribute (eg. mangrove, area etc) below these are unacceptable. Those for the "very high suitability" class boundary give minimum values which should be aimed for on sites of high conservation value or when possible. There is an additional column which shows the lowest of the low - the lower 95% confidence interval of the "suitable habitat" class boundary. This value defines unacceptable levels of the habitat attributes and is labelled "low suitability".

In summary, the mean models therefore give:

(i) a minimum acceptable value under any circumstances;

Fig. 2.1

Method for determining mean guide values by geometric mean regression (GMR). Example is Bar-tailed Godwit number and area-of-flat, showing the regression line (dashed), the approximate 95% confidence limits (dotted), and the prediction for the minimum and mean area-of-flat guide values for 'suitable habitat' based on the bird number class boundary (over 6 godwits).



(ii) a conservative minimum range of target values for areas of lesser conservation significance ('suitable habitat'); and

(iii) a minimum range of target values to aim for where shorebird habitat conservation is a priority ('very high suitability'). This gives managers a range of guide values appropriate for different locations and circumstances.

Keeping Within the Data

It is implicit in the regression trends that values above (or below for negative trends) those quoted are better. This can only be assumed within the range of values measured in the study. Values beyond the ranges of the regression lines do not necessarily continue the trend (eg. salinity higher than seawater, vegetation cover greater than that encountered). All ranges given are from the minimum guide value stated in the models to the maximum measured value only. In other words, the data is interpolated, but not extrapolated (Ferrier & Smith 1990). Such limits to the measured sample are noted on the models where necessary. Models should be used within the limits of the gradients they are based on (Marcot 1986).

The main attributes and guide values (above the dotted lines in the tables) are for use in prescribing habitat requirements. Supplementary guide values are given below the dotted lines for correlated attributes or those not significant at the adjusted level but significant at $P <= 0.05$. The independent importance of these is not established, but the values are provided for guidance if these particular aspects of habitat are in question.

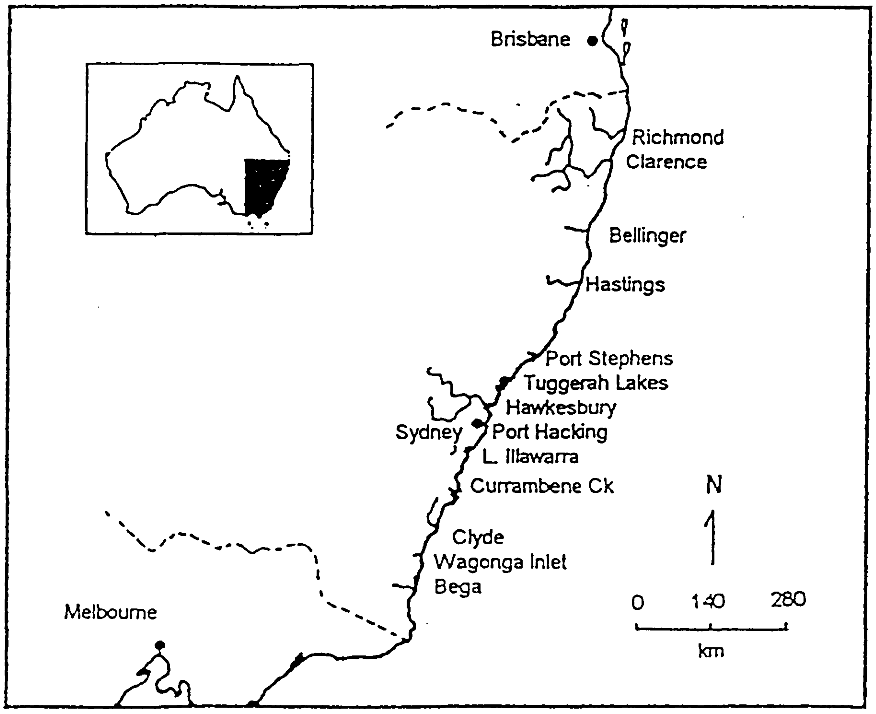
Testing the Mean Models

Because of their statistical nature, the mean models have a level of reliability built in (95% confidence intervals) (Mayer & Butler 1993), but they cannot be tested against any "known target values". However, to test the models' representativeness of all intertidal habitat in the region's estuaries, another set of regressions was made using an independent sample (Schamberger & O'Neil 1986; Poer 1993).

The independent data set of 43 intertidal flats was sampled randomly (without replacement) from a second subset of 13 different New South Wales estuaries from the stratified groupings (see Chapter 1: Methods: *Experimental Design*). This is "different place, different time" testing (Morrison *et al.* 1987). These flats were in the estuaries of the Richmond, Clarence, Bellinger, Hastings, Hawkesbury, Clyde and Bega Rivers, Wagonga Inlet, Currambene Creek (Jervis Bay), Port Stephens and Port Hacking, Lake Illawarra and Tuggerah Lakes (Fig. 2.2). These sites were censused for shorebirds once, and only habitat variables used in the models were measured.

Fig. 2.2

Locations of the sampled estuaries used to test
the habitat suitability models and assessment keys.



Both slope and starting point (elevation) of a regression line affect predicted values (Trexler & Travis 1993), so the regression coefficient (slope) and constant (starting point) were compared between the regression lines of the two samples. Comparison was done by calculating the 95% confidence interval for these two values for each line to test if they were significantly different (Sokal & Rohlf 1981; Zar 1984; Wardlaw 1985). Ordinary regressions were used because the confidence interval is the same for ordinary regression and geometric mean regression (Ricker 1984).

The mean model was considered reliable when (a) both regressions had significant slopes, and (b) neither the regression coefficient nor the constant were significantly different between the two samples at the 95% confidence level. A further test was made by a generalised linear model to test homogeneity of slope, using the interaction of the factor "sample" and the covariate "habitat variable", expressed as a P value ($P <= 0.05$) (McCullugh & Nelder 1983; Minitab Inc. 1991). (Results of these tests are also reported in the species accounts in Chapter 1, but only when a variable failed to meet the test requirements).

Disturbance Buffer Distances

Distances at which shorebirds were disturbed (Burger 1981,1986; Kingsford 1990; Pfister *et al.* 1992) were estimated in opportunistic observations of disturbance (not induced by the observer) during the field work. Disturbance was defined as an interruption to feeding, whether the bird flew or not. The source of each disturbance was noted. Distances for Bar-tailed Godwit, Eastern Curlew and Greenshank were tabulated according to disturbance sources. Patterns of high or low key sources of disturbance were identified according to distances, and tested for significance by F and t -tests ($P <= 0.05$, two-tailed). The same classes of disturbance (High or Low key) were used with less abundant species for which there were insufficient sample sizes for analysis.

Minimum buffer distances were derived from the upper 90% confidence interval of the mean disturbance distance for each species (a one in ten chance of being disturbed at this distance), for both high and low classes, plus an arbitrary 10 metres (to avoid the disturbance). To provide guidelines for less abundant species, the longest observed disturbance distance plus 10 metres was used if there was insufficient data for realistic confidence intervals. The sample size, often small, is given. For two species, the observer estimated low key disturbance distances by approaching a group of birds on foot. Distances based on these small samples are intended to provide interim guidelines, until the NSW Wader Study Group data base on disturbance can give more information (Straw 1994).

Elevation Heights

Average guide values for the elevation levels of intertidal flats were determined, for construction or restoration of shorebird feeding habitat (Davidson 1984; Wilcox 1986) in southeast estuaries with a roughly

2 metre tidal range. Thirteen natural tidal flats were surveyed with a laser level (Spectra-Physics Laserplane, Inc. 1991) and the levels related to a 'biological datum'. The flats were in the Pambula (2), Shoalhaven/Crookhaven (4), Georges (2), Hunter (2), Manning (2) and Macleay (1) estuaries.

The datum was the ground level of the lowest sedge (Cyperaceae), rush (Juncaceae) or saltcouch (*Sporobolus*) plants (Adam & Barclay 1981) growing at the closest shoreline. This datum was used because it reflected the mean high tide level and it did not need elaborate and potentially costly surveying techniques relating estuaries. It was hypothesised that the variance in the measured heights caused by this approximate datum would be within the range of 'normal' low tides, and therefore within useful guide-value limits. This hypothesis was tested by *t*-test of the mean height between the datum and the dry/wet interface (*(ii)* below) and accepted before guide values where further developed.

Heights were measured on one transect across each flat from shore to shallow (<500mm deep) water on the bottom of low tide (tides of 0.3m to 0.6m at Middle Head only (Public Works 1991)). On flats not adjoining land the transect was from water to water and the datum from the nearest vegetated shore was related to the flat height by water level (within 15 minutes to minimise water level change). Two heights were measured, to relate flat topography to the wetness classes used in the modelling:

(i) the height from the datum to the highest wet ground (pools excluded) (see Elevation Profile variables, Chapter 1); and

(ii) the height from the highest wet ground to the highest shallowly covered ground (noticeably inundated by water - about 2-3mm). The height of ground under deeper water can be measured by the water level.

Heights are reported as means +/- 95% confidence intervals, and are intended as an approximate guide which can be fine tuned as construction proceeds. The height from the datum to the lowest mangrove was also measured on 17 flats. The range of measurements was used to give a mean lowest level of mangrove growth for colonisation management.

Results and Discussion

Habitat Suitability Mean Models

In this section each model is presented (Tables 2.2,4,6,9,12,14 and 16 plus the composite 2.18), described and discussed. For brevity only the Bar-tailed Godwit model is fully explained, by way of example. Notes are provided for the other models where they aid interpretation of the guide values. Issues relating to the actual guide values are discussed in the General Discussion. Modelling approaches are discussed in Chapter 3: *Discussion*, and the General Introduction.

Bar-tailed Godwit:

The regression line and its 95% confidence interval (Fig. 2.1, above) predicted, for example, a tidal flat area of 10.5 ha + or - 2 hectares, for a count of 7 godwits (the arbitrary godwit number used for 'Suitable' habitat class boundary (Table 2.1)). This is not to say that only flats of 10.5ha will have 7 godwits. It implies a 95% chance that this size range is the most likely to support 7 feeding godwits, based on the study's sample.

The prediction is used to assign a value to this attribute of habitat (flat area of 10.5 ha + or - 2 hectares) which can be aimed for in the conservation management of Bar-tailed Godwit feeding habitat. If this size range is maintained on a flat, or provided, then it is likely that this aspect of godwit feeding habitat, capable of supporting this approximate level of use, will be conserved. Values were assigned in the same way for 55 godwit (very high habitat suitability class boundary) and each of the other attributes significantly related to Bar-tailed Godwit numbers (Table 2.2).

Because the suitability class boundaries are lower threshholds (they assume more birds are better), the habitat values represent the minimum values to be conserved and imply that higher values are better. The exception is in negative relationships such as % dry ground, where lower is better.

The lower 95% confidence limit of the lower guide value (for suitable habitat) was 8.5ha. This indicates that the mean trend in godwit number over all flats of less than 8.5ha will be (with a 95% chance) less than 7 godwit, which is very low in the context of the species' abundance in the region and flocking behaviour. This value can be regarded as a minimum, and reduction of flat area to smaller than this is likely to cause inadequate habitat. The equivalent lowest guide value for % dry was 76%*, that is, proportions of dry ground at low tide greater than 76% are unacceptable as

Table 2.1

Habitat Suitability classes, based on bird numbers on the 63 intertidal study flats, used for the guide values.

Habitat suitability class*:	Low	Suitable	Very High
Species			
Bar-tailed Godwit	6 or less	7 - 54	55 +
Whimbrel	none	1 - 2	3 +
Eastern Curlew	none	1 - 6	7 +
Greenshank	none	1	2 +
Tattler	none	1 - 2	3 +
Pacific Golden Plover	none	1 - 2	3 +
Species number	1 - 2	3+	n/a

* Low: unacceptable to allow value to fall this low, or site could be enhanced for shorebirds;

Suitable: value should be aimed for or maintained as a minimum acceptable level in areas or situations of lower priority for shorebird (or particular species) conservation;

Very High: value to aim for where shorebird conservation is a high priority.
n/a = not assessed - the distinction between suitable habitat and very high suitability was not possible for species number.

*61% + 15%

Table 2.2

Bar-tailed Godwit Habitat Suitability Mean Model

Minimum guide values to aim for when conserving and constructing Bar-tailed Godwit feeding habitat in southern East Coast estuaries (see footnote and explanations in text). Not for assessing existing habitat. Classes are based on: Low Suitability = less than 7 birds; Suitable = 7 to 54 birds; Very High Suitability = 55 or more birds. For measurement techniques see Appendix II.

HABITAT ATTRIBUTE	LOW SUITABILITY	SUITABLE	VERY HIGH SUITABILITY
Area of intertidal flat	smaller than 8.5 hectares	10.5 ha +/- 2 ha or larger	21 ha +/- 6 ha or larger
***% dry ground at low tide**	more than 76%	61% +/- 15% or less	16% +/- 11 % or less
- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -
% open water surrounding flat	less than 39%	46% +/- 7% or more	82% +/- 36%
Total Habitat Area within 1 kilometre	smaller than 35 ha	40 ha +/- 5% or larger	67 ha +/- 20 ha or larger

For the assessment of conservation value of flats, see Chapter 3. The supplementary habitat attributes below the dotted line are correlated with one or more above (see Chapter 1). %Dry are maximum guide values because of negative relation (less dry ground is better habitat). All these values are derived from the central trend and do not account for variation among individual flats. +/- values are the 95% confidence limits of the central trend (Geometric Mean Regression line).

* The second model-testing sample did not confirm the importance of this habitat attribute, but did confirm the guide values (see *Testing the Bar-tailed Godwit Habitat Suitability Mean Model*, below).

management criteria, and the minimum to be aimed for is 61%. Better minimum values, especially where godwit habitat conservation is a management priority, are the mean guide values for very high suitability habitat (over 55 godwit): 21 ha +/- 6 ha flat area, and 16% +/- 11% proportion of dry ground at low tide. Guide values for all other significant attributes of habitat are given, for guidance in their management.

Testing the Bar-tailed Godwit Habitat Suitability Mean Model

Comparison of the regressions from the modelling sample and an independent sample (see Methods) showed that flat area was also significantly ($P < 0.05$) related to Bar-tailed Godwit numbers in the independent sample (Table 2.3). There were no significant

Table 2.3

Equations for **Bar-tailed Godwit** number regressed against flat area and proportion of dry ground, as used *in the model, and comparisons with similar regressions based on the independent sample.*

Flat Area:

	Equation	*df*	R^2%	*F*	P
Modelling sample:	BTG No.= -0.1369+1.0012Area	1/59	23.2	18.79	0.000
Testing sample:	BTG No.= -0.1187+0.9094Area	1/41	21.3	21.3	0.001

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=60*) and independent sample (n=43).

	a	*b*
n=60	-0.6112, +0.3074	0.5486, 1.4538
n=43	-0.6252, +0.3878	0.4029, 1.4156

Results of generalised linear model:
Godwit number = sample flat area sample crossed with flat area,
the covariate being flat area.

	df	*F*	P
sample	1/99	0.00	0.96
area		31.02	0.000
sample crossed with area		0.07	0.789

(null hypothesis $H_0: b_1=b_2$ not rejected)

* three Fullerton Cove sites excluded (see text).

%Dry at low tide:

	Equation	*df*	R^2%	*F*	P
Modelling sample:	BTG No.= 1.1655 -.0094%Dry	1/56	10.6	7.74	0.007
Testing sample:	BTG No.= 1.1365 -.0068%Dry	1/40	2.6	2.1	0.155

95% confidence intervals of *a* (elevation) and *b* (slope) for modelled sample (n=58*) and independent sample (n=42#).

	a	*b*
n=58	0.8585, 1.473	-0.0162, -0.0027
n=42	0.7199, 1.5541	-0.0161, +0.0025

Results of generalised linear model:
Godwit number = sample %dry area sample crossed with %dry area,
the covariate being %dry area.

	df	*F*	P
sample	1/93	0.9	0.346
%dry		13.15	0.000
sample crossed with %dry		1.57	0.213

(null hypothesis $H_0: b_1=b_2$ not rejected)

*three Fullerton Cove sites excluded (see text): missing data.

#one site (opp. Snapper Pt., Clyde River estuary) excluded because of neap tide.

differences in the coefficients (slopes) or constants (elevations) between the two samples.

Percentage of dry ground at low tide was not significantly related to godwit number in the second sample, but the constants and coefficients were not significantly different to those in the modelling sample. The implication is that the aim values are appropriate if there is a relationship between godwit number and % dry ground at low tide, but the relationship is not verified by the second (though smaller) sample. The generalised linear model (GLM) showed no difference between the two samples in the relationships between Bar-tailed Godwit numbers and either attribute of habitat (Table 2.3).

Whimbrel:

Regressions: Fig.2.3; guide values Table 2.4.

Because Secchi measure decreases with increased sediment load, the relationship is negative and the guide values for Secchi transparency are maximums. These values for sediment regime apply to the maintenance of natural regimes, not the inflow of sediment which is harmful in content, or which constitutes a sudden change of the natural regime which might change flat profile or affect infauna (see General Discussion).

Table 2.4

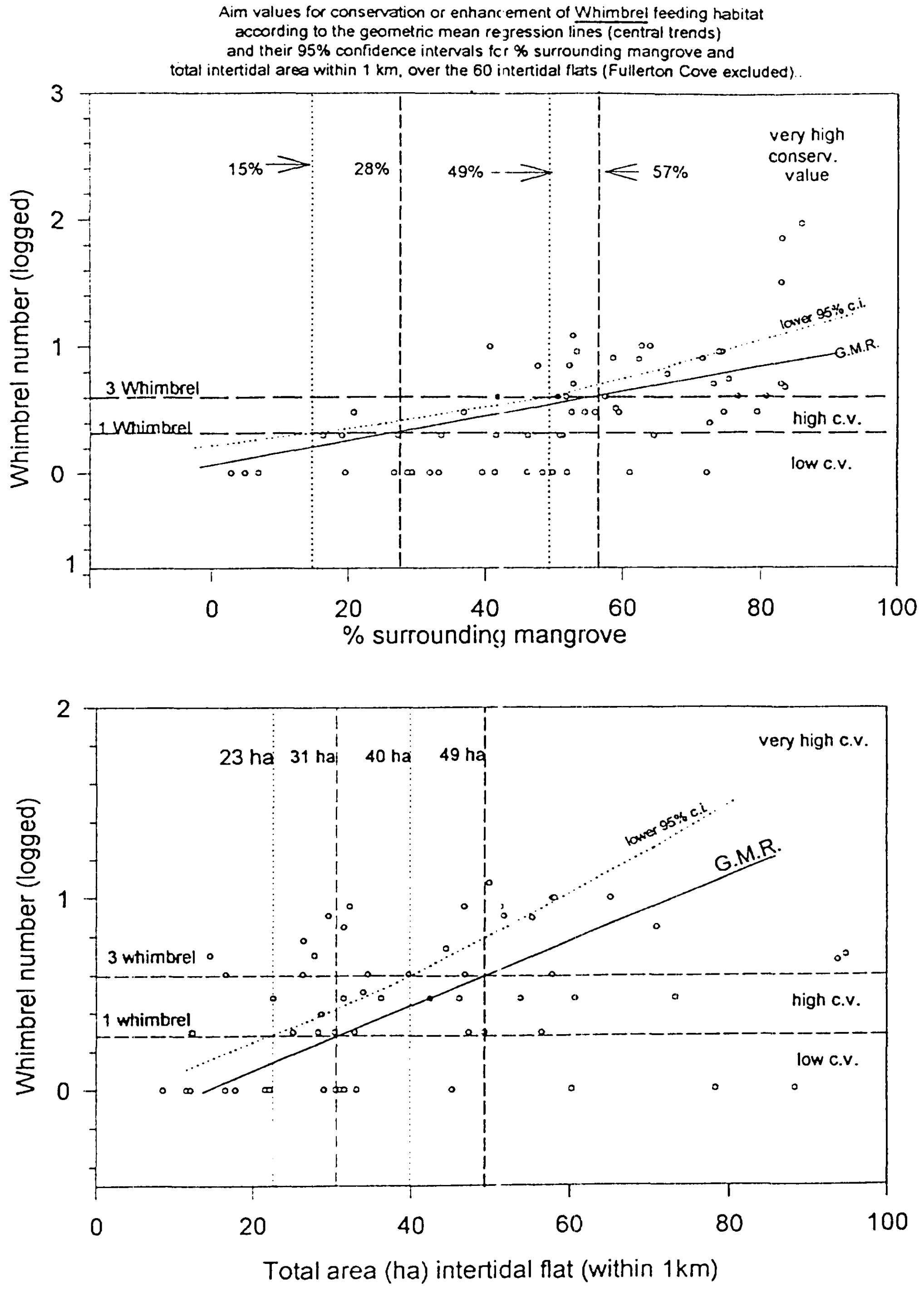
Whimbrel Habitat Suitability Mean Model

Minimum guide values to aim for when conserving and constructing Whimbrel feeding habitat in southern East Coast estuaries. Not for assessing existing habitat. Low Suitability = no birds; Suitable = 1-2 birds; Very High Suitability = 3 or more birds. For measurement techniques see Appendix II.

HABITAT ATTRIBUTE	LOW SUITABILITY	SUITABLE	VERY HIGH SUITABILITY
% Surrounding mangrove	less than 15%	28% +/- 13% or more	57% +/- 8% or more
---------------	---------------	---------------	---------------
Secchi transparency of adjacent water (natural sediment)	over 1.7 metres	1.3 m +/- 0.4 m or less	0.6 m +/- 0.6 m
***Total habitat area within 1 kilometre (including subject flat)**	less than 23 hectares	31 ha +/- 8 ha or more	49 ha +/- 9 ha or more
Area of surrounding habitat within 1 kilometre (excluding subject flat)	less than 28 ha	33 ha +/- 5 ha or more	48 ha +/- 15 ha or more
% dry ground at low tide	more than 56%	47% +/- 9% or less	17% + 20% ,-17%

For the assessment of conservation value of flats, see Chapter 3. The supplementary habitat attributes below the dotted line are either correlated with one or more above or *not significant at the adjusted ($P<=0.01$) significance level (see Chapter 1). Secchi transparency and % dry are maximum guide values because of negative relations (lower Secchi (less clear) and less dry ground, is better habitat). All values are derived from the central trend and do not account for variation among individual flats. +/- values are the 95% confidence limits of the central trend (Geometric Mean Regression line).

Fig. 2.3


Aim values for conservation or enhancement of Whimbrel feeding habitat
according to the geometric mean regression lines (central trends)
and their 95% confidence intervals for % surrounding mangrove and
total intertidal area within 1 km, over the 60 intertidal flats (Fullerton Cove excluded).
Whimbrel number (logged)
% surrounding mangrove
15%
28%
49%
57%
very high conserv. value
lower 95% c.i.
G.M.R.
3 Whimbrel
1 Whimbrel
high c.v.
low c.v.
Whimbrel number (logged)
Total area (ha) intertidal flat (within 1km)
23 ha
31 ha
40 ha
49 ha
very high c.v.
lower 95% c.i.
G.M.R.
3 whimbrel
1 whimbrel
high c.v.
low c.v.

Testing the Whimbrel Habitat Suitability Mean Model

The proportion of surrounding mangrove remained significantly related ($P < 0.05$) to Whimbrel numbers in the independent sample, and there was no significant difference in the slopes or elevations between the two (Table 2.5). The total area of intertidal flat within 1 km was not significantly related to Whimbrel number in the second sample, although there was a significant relation between Whimbrel number and the very similar measure - area of surrounding flats within 1 km. The slopes and elevations were not significantly different.

Table 2.5

Equations for **Whimbrel** number regressed against surrounding mangrove fringe and total intertidal area, as used in the model, and comparisons with similar regressions based on the independent sample. (Secchi transparency was not measured in the second sample).

% Surrounding Mangrove:

		df	R^2%	*F*	P
Modelling sample:	WBL No.=-0.0326+0.0098%Mngr	1/58	27.1	22.94	0.000
Testing sample:	WBL No.= 0.0047+0.0071%Mngr	1/41	17.0	9.61	0.003

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=60*) and independent sample (n=43).

	a	*b*
n=60	-0.2445, +0.1793	0.0051, 0.0139
n=43	-0.2048, +0.2142	0.0117, 0.0025

Results of generalised linear model:
Whimbrel number = sample %mangrove sample crossed with %mangrove
the covariate being %mangrove.

	df	*F*	P
sample	1/99	0.06	0.806
%mangrove		30.74	0.000
sample crossed with %mangrove		0.82	0.367

(null hypothesis $H_0: b_1=b_2$ not rejected)

* three Fullerton Cove sites excluded (see text).

Total Area of intertidal flat (within 1 km)

		df	R^2%	*F*	P
Modelling sample:	WBL No.=-0.4507+0.5773TArea	1/58	14.8	11.26	0.001
Testing sample:	WBL No.=-0.1824+0.2925TArea	1/41	3.1	2.36	0.132
(Test sample using area of surrounding flats within 1 km:	WBL No.=-0.2208+0.3644SArea	1/41	8.1	4.7	0.036)

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=60*) and independent sample (n=43).

	a	*b*
n=60	-0.9862, 0.0848	0.2361, 0.9186
n=43	-0.7933, 0.4285	0.6705, -0.0855

Results of generalised linear model:
Whimbrel number = sample Tot.area sample crossed with Tot.area.
the covariate being Tot.area.

	df	*F*	P
sample	1/99	0.44	0.510
Tot.area		11.63	0.001
sample crossed with Tot.area		1.25	0.267

(null hypothesis $H_0: b_1=b_2$ not rejected)

*three Fullerton Cove sites excluded (see text)

The implication is that the aim values are appropriate if total area is the best attribute to use, but area of surrounding flats (irrespective of the area of the flat in question) may be a better indicator of Whimbrel habitat. The two attributes are so similar, and correlated, that valid management decisions can be based on either. Covariance analysis indicated that there was no significant difference between the samples.

Eastern Curlew:

Regression: Fig.2.4; guide values Table 2.6.

Southern east coast estuaries are an important part of the range of Eastern Curlew (Smith 1991), so low numbers were used for the habitat suitability classes despite the abundance of the birds on the study flats. Main guide values are given for the total area of tidal flat within 1km. All other significant attributes were correlated with this, so they were listed as supplementary guide values and may merely reflect the general availability of feeding habitat. No minimum was defined for some. For example, area of flat has no lower guide value because curlews used flats down to the minimum area in the study: 1 hectare.

The conductivity of seawater (about 58 mS/cm or 37g/l (Dakin & Bennett 1987)) was the maximum measured on the sample of natural flats (see *General Discussion*). So the water conductivity (salinity) gradient has a natural upper limit beyond which suitability cannot be defined.

The percent of open water surrounding the flat is a measure of a flat's position in relation to surrounding land, and is correlated with area measures and salinity (Table 1.2, Fig. 1.2) Open flats had higher salinity and were larger. The guide values for very high suitability (62% + or - 14% open water) can be applied to proposals for walls, landfill etc. in conjunction with area and salinity guide values. Such correlated attributes should not be used to modify existing habitat because (a) their independent significance is not established, and (b) attributes of habitat

Fig. 2.4

Eastern Curlew habitat suitability mean model class boundaries and guide values for total habitat area within 1 km, according to geometric mean regression of 60 study flats (excluding Fullerton Cove).

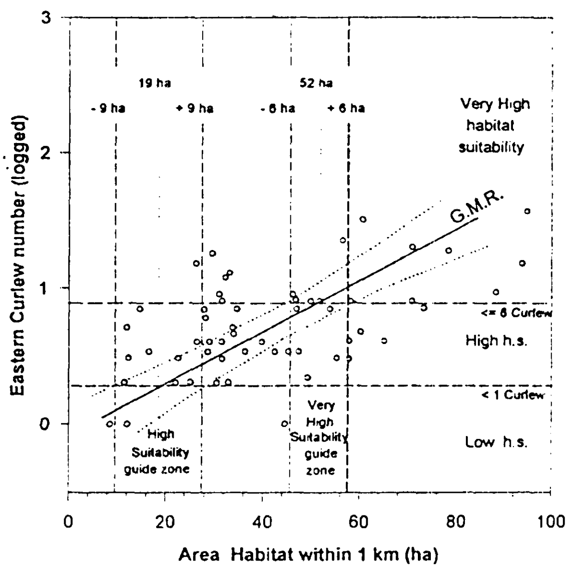


Table 2.6

Eastern Curlew Habitat Suitability Mean Model

Minimum guide values to aim for when conserving and constructing Eastern Curlew feeding habitat in southern East Coast estuaries.Not for assessing existing habitat.Low Suitability = no birds; Suitable = 1 to 6 birds; Very High Suitability = more than 6 birds. For measurement techniques see Appendix II.

HABITAT ATTRIBUTE	LOW SUITABILITY	SUITABLE	VERY HIGH SUITABILITY
Total habitat area within 1 kilometre (including subject flat)	less than 10 hectares	19 ha +/- 9 ha or more	52 ha +/- 6 ha or more
----------------	---------------	---------------	---------------
Area of Flat in hectares at mean low tide	no lower limit (minimum study site area 1 hectare)	2 ha +(-) 4 ha	14 ha +/- 3 ha
Area of surrounding habitat within 1 kilometre (excluding subject flat)	less than 4 ha	13 ha +/- 9 ha or more	40 ha +/- 6 ha or more
Perimeter length of flat in kilometres at mean low tide	no lower limit defined	no lower limit defined (1km +/- 1km or longer)	3 km +/- 0.7 km or longer
Mean Salinity in grams per litre (see Appendix 1)	16 g/l or less	22 +/- 6 g/l or more to natural seawater limit (appr.37 g/l)	35 +/- 4 g/l or more to natural seawater limit (appr. 37 g/l)
% Open Water surrounding flat (degree of enclosure by land)	no lower limit (1% - some connection to estuary implied)	no lower limit defined (19% +/- 18% or more)	62% +/- 14% or more

For assessment of conservation value of flats, see Chapter 3. The supplementary habitat attributes below the dotted line are correlated with the one above (see Chapter 1). Mean conductivity values relate to the salinity gradient from fresh to natural seawater; hypersaline values were not measured in the study. All guide values are derived from the central trend and do not account for variation among individual flats. +/- values are the 95% confidence limits of the central trend (Geometric Mean Regression line).

important for other species need to be considered (see General Discussion).

Testing the Eastern Curlew Habitat Suitability Mean Model

The total area of intertidal flat within 1 km was also significantly related ($P < 0.05$) to Eastern Curlew numbers in the independent sample (Table 2.7), and the slopes and elevations were not significantly different. Covariance analysis indicated that there was no significant difference between the samples.

However the confidence intervals of the coefficients only just overlapped, so a check was made by developing a model from the testing sample and comparing guide values from both models (Table 2.8). Those from the second sample were higher, and areas suggested for very suitable habitat (> 6 curlew) were very large (mean of 100 ha). The guide values from the original model have been retained. They were based on a larger dataset (three counts on 63 flats) and data inspection showed that sites with > 26ha had the potential of very high suitability (Fig. 3.10), so the guide values were considered reasonable.

Table 2.7

Equation for **Eastern Curlew** number regressed against total intertidal area, as used in the model, and comparisons with similar regressions based on the independent sample. The confidence intervals only just overlap.

Total Area of intertidal flat (within 1 km)		*df*	R^2%	*F*	P
Modelling sample:	ECW No.=-0.7774+0.9432TArea	1/58	35.0	32.74	0.000
Testing sample	ECW No.=-0.3309+0.4771TArea	1/41	13.4	7.50	0.009

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=60*) and independent sample (n=43).

	a	*b*
n=60	-1.2905, -0.2643	0.6162, 1.2701
n=43	-0.8894, 0.2276	0.1315, 0.8227

Results of generalised linear model:
Curlew number = sample Tot.area sample crossed with Tot.area, the covariate being Tot.area.

	df	*F*	P
sample	1/99	1.38	0.242
Tot.area		35.4:	0.000
sample crossed with Tot.area		3.8:	0.054

(null hypothesis $H_0: b_1=b_2$ not rejected)

*three Fullerton Cove sites excluded (see text)

Table 2.8

Comparison of guide values generated from two independent samples of intertidal flats, for Eastern Curlew habitat management.

Habitat Attribute	Low Suitability	Suitable	Very High Suitability
Total area of intertidal flat within 1 km (ha.): Main sample (*n*=63)	10	19 +/-9	52 +/-6
Independent Sample (*n*=43)	21	29 +10/-7	100 +115/-53

Less Abundant Species

Greenshank:

Regression: Fig. 2.5; guide values: Table 2.9.

The small number of flats used by Greenshank led to broader guide 'ranges' for this species. This and the low numbers of Greenshank on the flats should be borne in mind when using the guide values (see also Chapter 1: Results: *Less Abundant Species*). Trends should not be extrapolated beyond the ranges recorded in the study for either habitat or Greenshank number. Surrounding mangrove and proportion of wet ground are the main attributes used, plus several supplementary ones.

Mangrove cover *on* the flat, for example, had a weak trend influenced strongly by one site (Ryan's Creek, Shoalhaven estuary) where 14 Greenshank coincided with 20% cover of mangrove seedlings. Mangrove cover was correlated with surrounding mangrove, so its independent effect on habitat suitability cannot be gauged. High habitat suitability was indicated with mangrove cover guide values down to 1%, and very high suitability guide values were 9% + or - 7%. Mangrove cover beyond the maximum recorded of 20% (seedlings) may not continue the trend, or may reverse it by displacing feeding habitat.

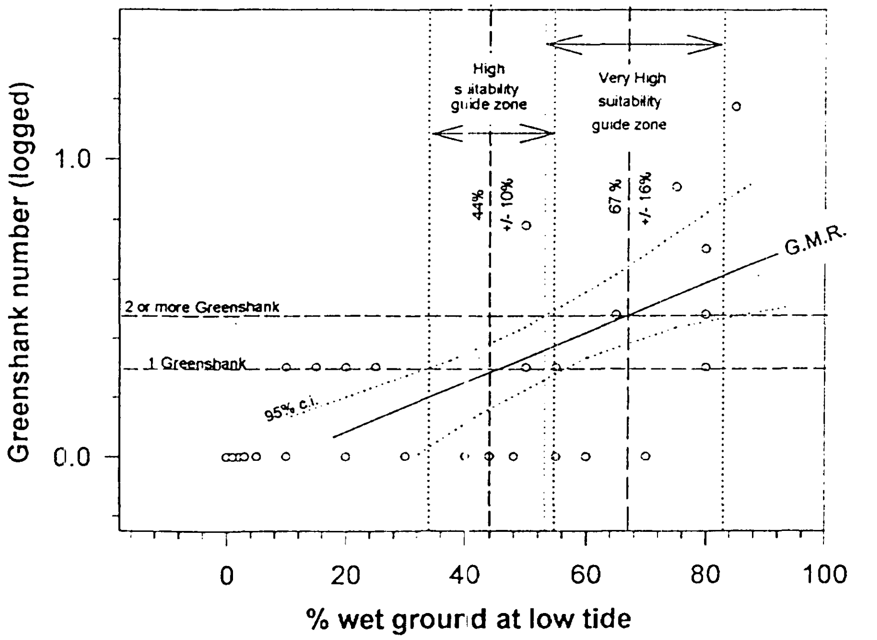
Greenshank were found to be more nocturnal than other species (see Chapter 4). The model, based on diurnal numbers, may overestimate guide values if more Greenshank used the sample flats at night.

Testing the Greenshank Habitat Suitability Mean Model

There was no relationship between Greenshank number and % wet ground at low tide over the whole second sample (Table 2.10). Inspection of the data showed that flats in the modelled sample were "dry" if they were not "wet" (Table 2.11), creating the relationship, whereas in coastal lagoons (Lake Illawarra, Tuggerah Lake) in the second sample, flats that were not "wet" were shallow (also Greenshank habitat).

Fig. 2.5

Greenshank habitat suitability guide values for high and very high habitat suitability class boundaries and the two significant habitat attributes according to geometric mean regression.



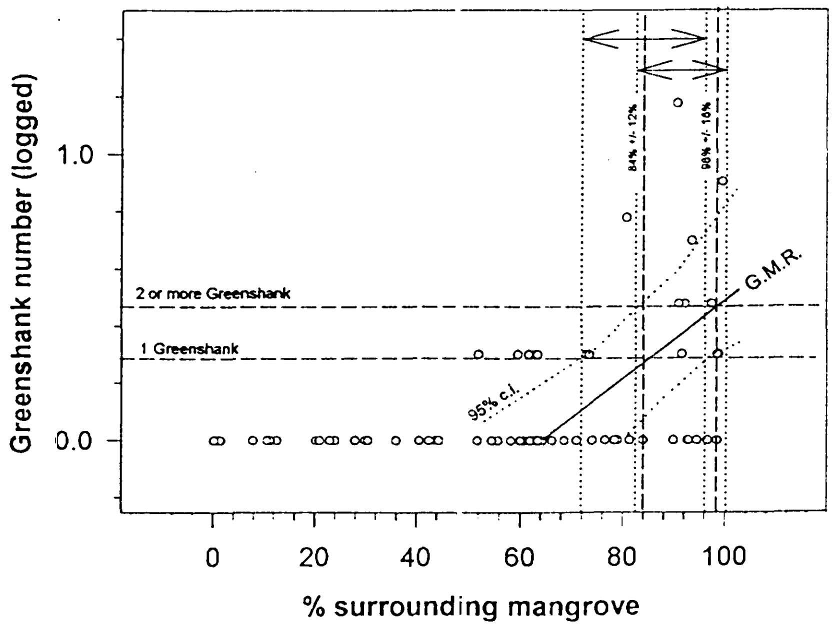


Table 2.9

Greenshank Habitat Suitability Mean Model

Minimum guide values to aim for when conserving and constructing Greenshank feeding habitat in southern East Coast estuaries. Not for assessing existing habitat. Low Suitability = no birds; Suitable = 1 bird; Very High Suitability = 2 or more birds. For measurement techniques see Appendix II.

HABITAT ATTRIBUTE	LOW SUITABILITY	SUITABLE	VERY HIGH SUITABILITY
% wet ground at mean low tide	34% or less	44% +/- 10% or more	67% +/- 16% or more
% surrounding mangrove	72% or less	84% +/- 12% or more	98% +2%,- 16%
- - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -
% Open Water surrounding flat (degree of enclosure by land)	42% or more	26% +/- 16% or less	11% +27%, - 11%
% mangrove cover on flat (range measured: 0 to 20% only)	1% or less (some mangrove presence on flat implied)	4% +/- 3% or more	9% +/- 7% or more
% dry ground at mean low tide	32% or more	19% +/- 13% or less	3% +15%, -3%
Secchi transparency (metres of vertical visibility) of associated waters (see Apx.1)	1.7 metres or more	1.3m +/- 0.4m or less	0.6m + 0.7m, -0.6m
Suspended solids in associated water in mg/l (see Apx.1)	96 mg/l or less	167 mg/l +/- 71 mg/l or more	267 mg/l +/- 130 mg/l or more
Orthophosphate (PO_4) level of associated water in mg/l (Apx.1)	0.22 mg/l or less	0.38 mg/l +/- 0.16 mg/l or more	0.59 mg/l +/- 0.29 mg/l or more

For assessment of conservation value of flats for Greenshank, see Chapter 3. The supplementary habitat attributes below the dotted line are correlated with one or more above (see Chapter 1). % open water, % dry and Secchi transparency values are maximum guide values because of negative relations. All guide values are derived from the central trend and do not account for variation among individual flats. +/- values are the 95% confidence limits of the central trend (Geometric Mean Regression line). Guide values are limited to the ranges of habitat attributes (indicated) and Greenshank numbers (0-14) recorded in the study.

Table 2.10

Equations for **Greenshank** number regressed against proportion of wet ground at low tide and proportion of surrounding mangrove, as used in the model, and comparisons with similar regressions derived from the independent sample. % wet equations are shown with and without the sites where non-wet ground was shallowly inundated rather than dry.

%Wet at low tide:

	df	R^2%	*F*	P
Modelling sample: GSK No.=-0.0287+.0047%Wet	1/59	6.7	5.3	0.025
Testing sample:				
(All sites: GSK No.=0.1713+0.00004%Wet	1/41	0.0	0.0	0.990)
Shallow sites (coastal lagoons) excluded: GSK No.=-0.0437+0.0048%Wet	1/38	11.7	6.17	0.018

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=61*) and independent sample (n=40#).

	a	*b*
n=61	-0.1668, 0.1094	0.0005, 0.0089
n=40	-0.1903, 0.1023	-0.1903, 0.1023

Results of generalised linear model:
Grennshank number = sample %wet area sample crossed with %wet area, the covariate being %wet area.

	df	*F*	P (all sites)
sample	1/94#	0.03	0.854 (.091)
%wet		10.98	0.001 (.157)
sample crossed with %wet		0.03	0.853 (.165)

(null hypothesis $H_0: b_1=b_2$ not rejected)

*missing data.
three sites in coastal lagoons (2 in Lake Illawarra, 1 in Tuggerah Lake) with tidal restrictions excluded because their low %Wet values resulted from being shallowly flooded (suitable Greenshank habitat) rather than dry at low tide (unsuitable), as in the estuary sites, and therefore confounded the result (see text).

%Surrounding Mangrove

	df	R^2%	*F*	P
Modelling sample: GSK No.=-0.0946+0.0037%Mangr	1/61	17.6	14.22	0.000
Testing sample:				
(Not counting *Casaurina* trees: GSK No.=-0.0292+0.0038%Mangr	1/41	5.40	3.40	0.072)
Including Casaurina trees as ''mangrove'' **: GSK No.= -0.0343+0.0053%Mangr	1/41	12.3	6.87	0.012

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=61*) and independent sample (n=43).

	a	*b*
n=61	-0.2242, +0.0350	0.0017, 0.0057
n=43	-0.2790, +0.1512	0.0013, 0.0093

Results of generalised linear model:
Whimbrel number = sample %mangrove sample crossed with %mangrove, the covariate being %mangrove.

	df	*F*	P
sample	1/102	0.30	0.586
%mangrove		19.30	0.000
sample crossed with %mangrove		0.61	0.436

(null hypothesis $H_0: b_1=b_2$ not rejected)

** see text; * missing data.

Table 2.11

Pearson product-moment correlation coefficients for the three complementary measures of intertidal flat elevation above low tide: % dry ground at low tide, % wet ground, and % shallow (<50mm) water, for the 63 intertidal flats used in the modelling. The matrix is simply to illustrate that on estuarine tidal flats, proportions of wet ground were much more likely to be complemented by the proportion of dry ground than shallowly covered ground (see Greenshank: *Testing the Mean Model*). Critical value at $P = 0.05$ (two-tailed) = 0.248.

	%Wet	%Shallow
%Wet		0.012
%Dry	-0.684	-0.674

Because the data did not describe them adequately, these sites were omitted from the second sample. Without them, there was actually a stronger trend in Greenshank number with % wet ground at low tide (rather than dry) in the testing sample than in the modelling sample (Table 2.10). There was no significant difference ($P <= 0.05$) between either the slopes or the elevations of the two regression lines, with or without the sites in coastal lagoons, and the covariance check showed no difference in samples.

Shallow water area (at appropriate Greenshank feeding depth, <100mm) should be included in % wet ground estimates for lagoon sites. A similar situation arises with % surrounding mangrove, which are replaced by *Casaurina* (sometimes *Melaleuca*) in the less saline lagoons (see also Chapter 3: Testing the Range Models). To retain the relevance of the guide values for lagoons*, % surrounding *Casaurina* was included, effectively making the attribute "% surrounding littoral trees". This was also significantly related ($P <= 0.05$) to Greenshank numbers in the independent sample (Table 2.10). There was no significant difference in the slopes or elevations between the two samples, and no difference between the samples in the GLM.

Tattler (in estuaries):
Regression: Fig. 2.6; guide values: Table 2.12.

These guide values pertain to the estuarine habitats of Tattler. Grey-tailed Tattler also use reef habitats not dealt with in this study, and Wandering Tattler are thought to use mainly reef habitats, in the region (Lane 1987; Chafer 1995) (see General Discussion: *Regional Coverage and Application*).

* This excludes intermittently opening coastal lagoons, which are different and more variable because their connection with the sea changes (Pollard 1994). They have not been used in the development of the guide values, and are such a restricted and sensitive aquatic environment that they need special management.

Fig. 2.6

Feeding habitat suitability guide values for Tattler based on geometric mean regression of Tattler number and % adjoining mangrove on 63 intertidal flats (see Table Tatmod, text).

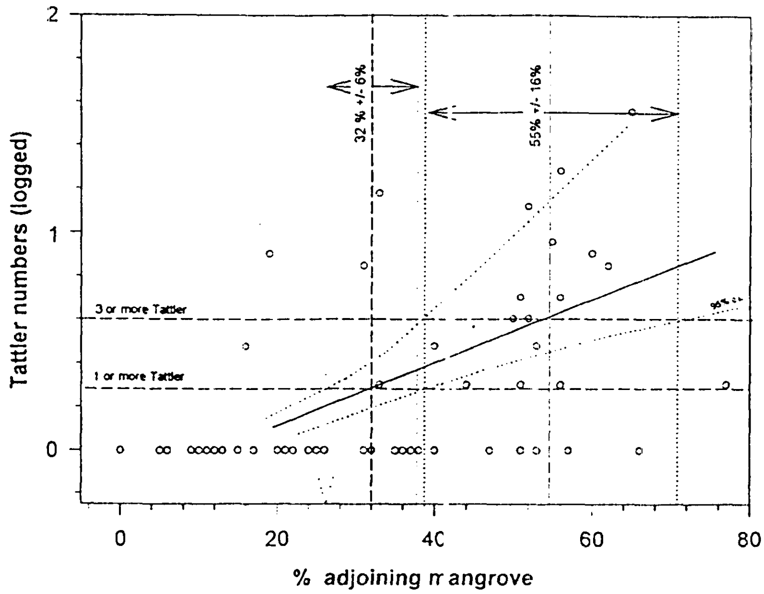


Table 2.12

Tattler Habitat Suitability Mean Model

Minimum guide values to aim for when conserving and constructing Tattler feeding habitat in southern East Coast estuaries. Not for assessing existing habitat. Low Suitability = no birds; Suitable = 1 or 2 birds; Very High Suitability = 3 or more birds. For measurement techniques see Appendix II.

HABITAT ATTRIBUTE	LOW SUITABILITY	SUITABLE	VERY HIGH SUITABILITY
% adjoining mangrove	26% or less	32% +/- 6% or more	55% +/- 16% or more
- - - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -
% Total ground cover (see Chapter 1)	16% or less	27% +/- 11% or more	56% +/- 35%
% mangrove cover on flat (range measured: *0 to 20% only*)	2% or less (some mangrove on flat implied)	4% +/- 2% or more	13% +/- 11% or more

For assessment of conservation value of flats for Tattler, see Chapter 3. The supplementary habitat attributes below the dotted line are correlated with the one above (see Chapter 1: Tattler). All guide values are derived from the central trend and do not account for variation among individual flats. +/- values are the 95% confidence limits of the central trend (Geometric Mean Regression line). Guide values are limited to the ranges of habitat attributes recorded in the study (as indicated).

The proportion of adjoining mangrove was the main attribute of intertidal estuarine flats used in the model, but two correlated aspects of cover were included. The guide values can be used for managing those specifically, bearing in mind that their independent importance is not established. Ground cover consists of mangrove seedlings, pneumatophores, seagrass, oysters, rocks and/or structures. The study did not assign relative importance to these elements. Mangrove cover (on the flat) guide values only extend to the maximum measured in the sample (20% cover).

Testing the Tattler Habitat Suitability Mean Model

Adjoining mangroves were also significantly related ($P < 0.05$) to Tattler numbers in the independent sample (Table 2.13). There was no significant difference in the slopes or elevations between the two samples, and no significant difference between the samples in the relationship between Tattler numbers and the proportion of adjoining mangrove.

Table 2.13

Equations for **Tattler** number (in estuaries) regressed against proportion of adjoining mangrove, as used in the model, and comparisons with similar regressions based on the independent sample.

% Adjoining Mangrove:	*df*	R^2%	*F*	P
Modelling sample:TAT No.=-0.1163+0.0108%AdjMgr	1/60	20.7	16.90	0.000
Testing sample: TAT No.=-0.0070+0.0107%AdjMgr	1/41	16.0	9.01	0.005

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=62*) and independent sample (n=43).

	a	*b*
n=62	-0.2974, +0.0648	0.0056, 0.0160
n=43	-0.1931, +0.1791	0.0036, 0.0178

Results of generalised linear model:
Tattler number = sample %AdjoinMangr sample crossed with %AdjoinMangr, the covariate being %AdjoinMangr.

	df	*F*	P
sample	1/101	0.70	0.404
%AdjoinMangr		24.87	0.000
sample crossed with %AdjoinMangr		0.00	0.969

(null hypothesis $H_0: b_1=b_2$ not rejected)

* one site, Quibray Bay, Georges R., ommitted from model (see text).

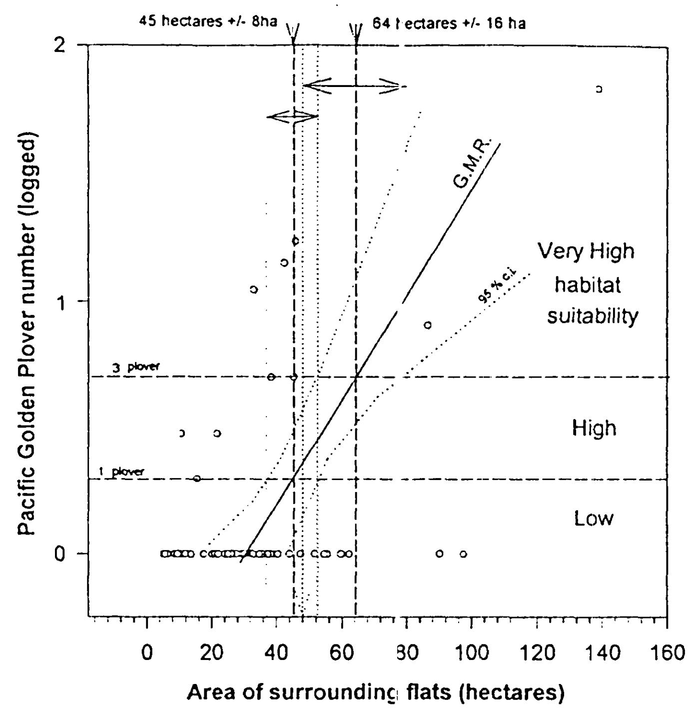
Pacific Golden Plover:

Regression: Fig. 2.7; guide values: Table 2.14.

The small number of sites used by Pacific Golden Plover (Table 1.3) resulted in a marginal ability to model habitat suitability for this species (Gove *et al.* 1982). The main attribute of habitat is the area of surrounding flats within 1km, and supplementary guide values are given for mean surface hardness, as this was significant (softer is better) when only used flats were analysed.

Fig. 2.7

Feeding habitat suitability guide values for Pacific Golden Plover based on geometric mean regression of plover number and area of surrounding flats within 1km, on 63 intertidal flats. The small proportion of flats used by plover results in displacement of the regression line and high guide values compared to values of habitat used by plover (see text, Discussion).



However, these trends were not present in the second model-testing sample (43 flats, 7 used - see below). These guide values can't be used with as much confidence as those for other species, which have been tested successfully with the second sample. They are conservative, however, because of the influence of unused flats on the geometric regression line.

Testing the Pacific Golden Plover Habtat Suitability Mean Model

Surrounding flat area was not significantly related ($P <= 0.05$) to Pacific Golden Plover numbers in the independent sample (Table 2.15), but there was no significant difference in the slopes or elevations, or in covariate analysis, between the two samples. This implies that the aim values are appropriate if there is a relationship between plover number and the area of surrounding habitat, but the relationship is not verified by the second, but smaller, sample.

Table 2.14

Pacific Golden Plover Habitat Suitability Mean Model

Minimum guide values to aim for when conserving and constructing Pacific Golden Plover feeding habitat in southern East Coast estuaries (see text). Not for assessing existing habitat. Low Suitability= no birds; Suitable = 1 or 2 birds; Very High Suitability = 3 or more birds. For measurement techniques, see Appendix II.

HABITAT ATTRIBUTE	LOW SUITABILITY	SUITABLE	VERY HIGH SUITABILITY
Area of surrounding flats within 1km	37 ha or less	45 ha +/- 8 ha or more	64ha +/- 16ha or more
- - - - - - - -	- - - - - - - -	- - - - - - - -	- - - - - - - -
Total area of intertidal flat within 1km	49 ha or less	64 ha +/- 15 ha or more	96 ha +/- 34 ha or more
***Mean Surface Hardness (kg/cm^2)**	2.12 kg/cm^2 or more	1.17 +/- 0.80 kg/cm^2 or less	0.89 +/- 1.23 kg/cm^2 or less

For assessment of the conservation value of flats for Pacific Golden Plover, see Chapter 3. The supplementary habitat attributes below the dotted line are either correlated with the one above (Total Area) or not significant at the adjusted (0.008) level (Hardness) (see Chapter 1). Guide values are derived from the central trend and do not account for variation among individual flats. +/- values are the 95% confidence limits of the central trend (Geometric Mean Regression line). * Based on the sample of 10 used flats only, causing wide confidence intervals which results in the apparent overlap of suitable and very high suitability ranges.

Table 2.15

Equation for **Pacific Golden Plover** number regressed against surrounding intertidal area, as used in the model, and comparison with a similar regression derived from the independent sample.

Area of Surrounding Flats within 1km:

		df	R^2%	*F*	P
Modelling sample:	PGP No.= -0.0974+0.0070Area	1/61	19.5	16.00	0.000
Testing sample:	PGP No.= -0.0007+0.0057Area	1/41	4.1	2.80	0.102

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=63) and independent sample (n=43).

	a	*b*
n=63	-0.2410, +0.0462	0.0035, 0.0104
n=43	-0.2380, +0.2394	0.0011, 0.0125

Results of generalised linear model:
Plover number = sample surr.area sample crossed with surr.area.
the covariate being surrounding area.

	df	*F*	P
sample	1/102	0.54	0.463
surrounding area		12.62	0.001
sample crossed with surr.area		0.13	0.722

(null hypothesis $H_0: b_1 = b_2$ not rejected)

Species Number (Use by Multiple Species):

Regressions: Fig.2.8; Guide Values: Table 2.16).

The habitat values given for the number of species on the sampled flats (all migratory shorebird species) can be applied as general shorebird habitat requirements in estuaries. Numbers of each species increased with species number (Table 1.9), so flats able to support more species of shorebirds are also likely to support more individuals of each species. This doesn't take into account requirements of species with special conservation status.

The aim is to define the attributes of habitat which support 'low' or 'high' numbers of shorebird species (3+ species is used as the class boundary (Table 2.1)), and to nominate values of these to help maintain or enhance the use of feeding grounds by multiple species of shorebirds, or as general guidelines for feeding habitat conservation in estuaries. The regression lines (plus or minus 95% confidence limits) for each significant attribute (Fig. 2.8) give minimum guide values for suitable habitat for 3 or more shorebird species, based on the high/low class boundary (Table 2.16).

Because Secchi measure decreases with increased sediment load, this relationship is negative and the guide values are maximums, with a lower limit restricted to the minimum measured in the study, 0.35m, beyond which shorebird habitat suitability cannot be assessed by this study. These values apply to the maintenance of natural regimes, not the inflow of sediment which is harmful in content, or constituting a change of the natural regime which might change flat profile or endanger infauna (see *General Discussion*).

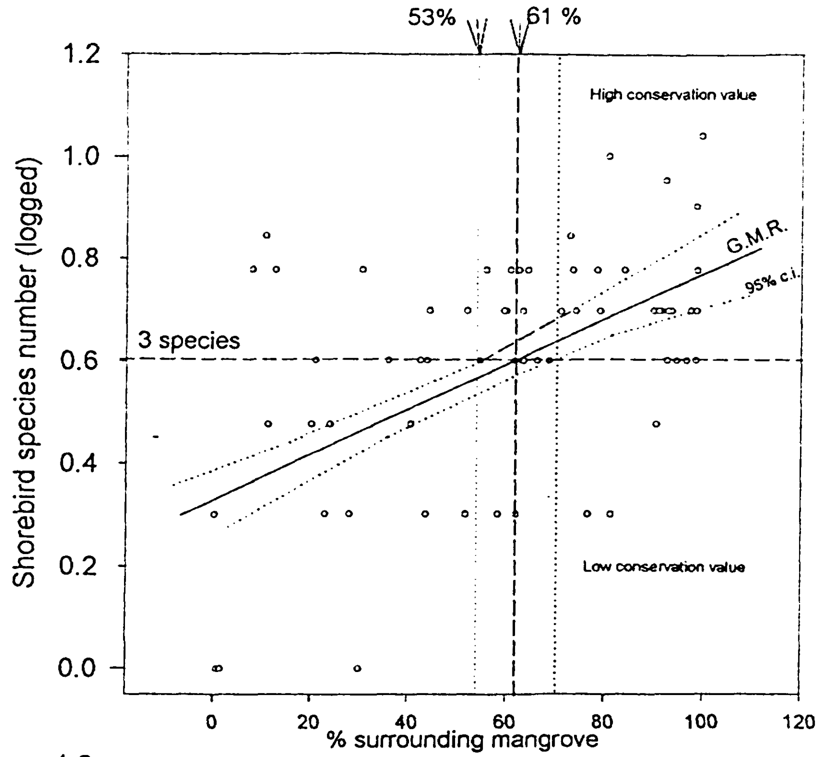
Testing the Species Number Habitat Suitability Mean Model

The modelling sample and independent testing sample were compared for the first four attributes used. All main relationships (not % shallow water at low tide) were also significantly related ($P < 0.05$) to species number in the independent sample (Table 2.17). There was no significant difference between the samples, and no difference between the slopes or elevations of any regression lines.

Proportion of shallow water at low tide was not significantly related to species number in the second sample, although the constants and coefficients were not significantly different between the regression lines (Table 2.17). The implication is that this supplementary value (which has a very wide zone of approximation due to its weak relationship with species number) is appropriate if % shallow ground is an appropriate

Fig. 2.8

Aim values for shorebird feeding habitat conservation and construction for high (3+) species number according to the geometric mean regression lines over the 63 study flats.



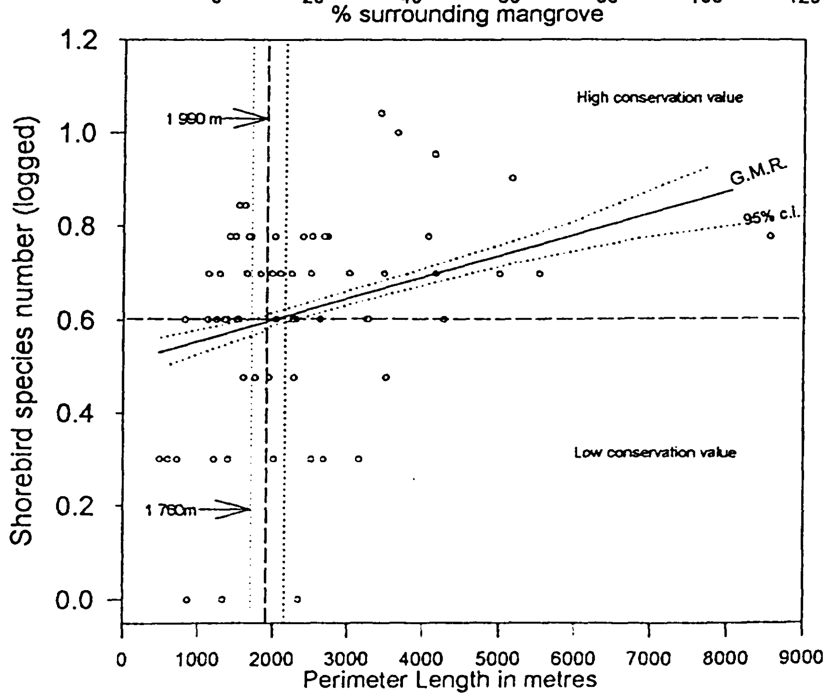


Table 2.16

Species Number Habitat Suitability Mean Model

(Habitat Suitability for Use by Multiple Species)

Minimum general guide values to aim for when conserving and constructing migratory shorebird feeding habitat in southern East Coast estuaries, based on 3 or more species using the area together (see text). Not for assessing existing habitat. To conserve feeding habitat of particular species or groups of species, see individual species guidelines. For measurement techniques see Appendix II.

HABITAT ATTRIBUTE	LOW SUITABILITY	SUITABLE
% Surrounding mangrove	less than 53%	61% +/- 8% or more
Perimeter Length	less than 1 750m	1 990m +/- 230m or more
Area of surrounding habitat within 1 kilometre (excluding subject flat)	less than 22 hectares	26ha +/- 4 ha or more
---------------	---------------	---------------
% shallowly covered (<50mm deep) ground at low tide	less than 18%	50% +/- 32% or more to measured maximum (80%)
Secchi transparency of adjacent water (natural sediment)	over 1.5 metres	1m +/- 0.5 m or less to measured minimum (0.35)
Total habitat area within 1 kilometre (including subject flat)	less than 33ha	39 ha +/- 6 ha or more

For assessment of the conservation value of flats, see Chapter 3. The supplementary habitat attributes below the dotted line are either correlated with one or more above or in the case of %shallow, significantly related to species number at $P<=0.05$ but not at the adjusted significance level of 0.008 (see Chapter 1 - Methods: *Significancee Level*). Secchi transparency is a maximum guide value because it is a negative relation, that is lower Secchi (less clear) is better habitat (see General Discussion and Appendix III Section 2). All values are derived from the central trend and do not account for variation among individual flats. +/- values are the 95% confidence limits of the central trend (Geometric Mean Regression line).

Table 2.17

Equation for **the number of shorebird species** regressed against surrounding mangrove, perimeter length, surrounding area and proportion of shallow water, as used in the model, and comparisons with similar regressions derived from the independent sample.

% Surrounding Mangrove:

		df	R^2%	*F*	P
Modelling sample:	Spp.No.= 0.3468+0.0049%Mngr	1/58	18.7	14.55	0.000
Testing sample:	Spp.No.= 0.3030+0.0048%Mngr	1/41	10.9	6.13	0.018

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=60*) and independent sample (n=43).

	a	*b*
n=60	0.2095, 0.4841	0.0023, 0.0075
n=43	0.1248, 0.4812	0.0010, 0.0086

Results of generalised linear model:
species number = sample %mangrove sample crossed with %mangrove
the covariate being %mangrove.

	df	*F*	P
sample	1/99	0.15	0.702
%mangrove		18.35	0.000
sample crossed with %mangrove		0.00	*0.970*

(null hypothesis $H_0: b_1=b_2$ not rejected)

* three Fullerton Cove sites excluded (see text).

Perimeter Length:

		df	R^2%	*F*	P
Modelling sample:	Spp.No.=-0.6187+0.3671PerimL	1/58	12.9	9.76	0.003
Testing sample:	Spp.No.=-1.5112+0.6154PerimL	1/41	21.6	12.55	0.001

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=60*) and independent sample (n=43).

	a	*b*
n=60	-1.3893, 0.1519	0.1340, 0.8333
n=43	-2.6360,-0.3869	0.2708, 0.9600

Results of generalised linear model:
Species number = sample Perim.Length sample crossed with Perim.L.,
the covariate being Perimeter Length.

	df	*F*	P
sample	1/99	1.80	0.182
Perimeter Length		23.55	0.000
sample crossed with Perim.L.		1.50	0.223

(null hypothesis $H_0: b_1=b_2$ not rejected)

*three Fullerton Cove sites excluded (see text)

Area of surrounding intertidal flat (within 1 km):

		df	R^2%	*F*	P
Modelling sample:	Spp.No.= 0.1442+0.3143SArea	1/58	13.3	10.03	0.002
Testing sample:	Spp.No.=-0.2321+0.5249SArea	1/41	30.0	19.01	0.000

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=60*) and independent sample (n=43).

	a	*b*
n=60	-0.1411, 0.4295	0.1175, 0.5111
n=43	-0.5718, 0.1076	0.2860, 0.7638

Results of generalised linear model:
Species number = sample Surround.area sample crossed with Sur.area,
the covariate being Surrounding area.

	df	*F*	P
sample	1/99	2.86	0.094
Surrounding area		29.41	0.000
sample crossed with Sur.area		1.85	0.177

(null hypothesis $H_0: b_1=b_2$ not rejected)

*three Fullerton Cove sites excluded (see text)

cont./...

Table 2.17 (cont.)

% Shallowly (<50mm)covered ground at low tide:		*df*	R^2%	*F*	P
Modelling sample:	Spp.No.= 0.4796+0.0057%<50mm	1/56	8.2	6.12	0.016
Testing sample:	Spp.No.= 0.4571+0.0011%<50mm	1/41	0.0	0.23	0.634

95% confidence intervals of elevation (*a*) and slope (*b*) for modelled sample (n=58*) and independent sample (n=43).

	a	*b*
n=58	0.3734, 0.5858	0.0011, 0.0103
n=43	0.2850, 0.6292	0.0035, 0.0057

Results of generalised linear model:
Species number = sample %shallow ground sample crossed with %Shallow, the covariate being %shallow ground.

	df	*F*	P
sample	1/97	0.05	0.821
%shallow ground		3.55	0.062
sample crossed with %shallow		1.64	0.204

(null hypothesis $H_0: b_1=b_2$ not rejected)

*three Fullerton Cove sites excluded (see text), missing data.

attribute to use, but the choice of attribute is not validated by the second sample, and the relationship with both samples combined was not significant.

Composite Guidelines:

A composite table (Table 2.18) shows the highest criteria among the species, for each attribute of habitat. For example, Whimbrel and Greenshank numbers are both associated with the amount of surrounding mangrove, but Greenshank numbers are associated with more mangrove. Only the higher Greenshank guide values are given in this table. It is therefore biased toward conservation of maximum values of the attributes, to cater for all species.

Other Guidelines

Construction Specifications

Table 2.19 contains recommended ranges of some attributes of habitat for the construction of shorebird feeding areas, based on natural habitat. Included are ranges for substrate properties, vegetation cover and water properties which did not show trends with bird numbers across the whole sample of flats. Rather, an acceptable range is inferred from the range found on the natural flats used in the study, and the shorebird use of the range extremities. Because only a few flats occupied the extremities of the ranges, these values

Table 2.18

Maximum Values

Guide values to aim for when conserving and constructing migratory shorebird feeding habitat in southern East Coast estuaries, based on values for the common species needing the most of each habitat attribute (see text). Note that this table is biased towards maximum values of each attribute. Not for assessing existing habitat. Low Suitability, Suitable and Very High Suitability class criteria varies with species concerned (as indicated).

HABITAT ATTRIBUTE	LOW SUITABILITY	SUITABLE	VERY HIGH SUITABILITY
Area of intertidal flat (Bar-tailed Godwit)	smaller than 8.5 hectares	10.5 ha +/- 2 ha or larger	21 ha +/- 6 ha or larger
Area of surrounding flats within 1km (Pacific Golden Plover)	37 ha or less	45 ha +/- 8 ha or more	64ha +/- 16ha or more
Total habitat area within 1 kilometre (including subject flat) (Eastern Curlew)	less than 10 hectares	19 ha +/- 9 ha or more	52 ha +/- 6 ha or more
% Surrounding mangrove (Greenshank)	72% or less	84% +/- 12% or more	98% +2%,- 16%
% adjoining mangrove (Tattler)	26% or less	32% +/- 6% or more	55% +/- 16% or more
% dry ground at low tide (Bar-tailed Godwit)	more than 76%	61% +/- 15% or less	16% +/- 11 % or less
% wet ground at mean low tide (Greenshank)	34% or less	44% +/- 10% or more	67% +/- 16% or more
Secchi transparency of adjacent water (natural sediment) (Whimbrel and Greenshank)	over 1.7 metres	1.3 m +/- 0.4 m or less	0.6 m +/- 0.6 m

For assessment of the conservation value of flats, see Chapter 3. No supplementary habitat attributes are given; only primary attributes for each species are used (see species tables). Secchi transparency and % dry are maximum guide values because of negative relations (lower Secchi (less clear) and less dry ground, is better habitat). For measurement techniques see Appendix II. All values are derived from the central trends for the species concerned and do not account for variation among individual flats. +/- values are the 95% confidence limits of the central trends (Geometric Mean Regression lines).

Table 2.19

Recommended attributes of constructed migratory shorebird feeding habitat. Values asterisked* have not been derived from analysis of the full sample, but rather from the range of values measured during the study (see text). They are therefore not statistically verified and are offered as interim guides only. For explanation of measurement units and instructions, see Appendix II.

Feeding Area Attribute	Minimum Value	Maximum Value
Size: **Area of flat (ha)** **Total area within 1km (ha)**	Size of constructed habitat is constrained by the project. The guide values in Table 2.18 should be used if possible. Smaller areas are worthwhile but their use by adequate numbers of shorebirds can't be guaranteed. Areas less than 3 ha* are unlikely to be used by worthwhile numbers of shorebirds.	no upper limit
Vegetation: **Proportion of Surrounding Mangrove (%)**	15% (Whimbrel minimum)	100%
Proportion of Mangrove Cover (% total foliage projection cover over flat area - see Appendix II))	no lower limit (bare)	*no upper limit to measured maximum of 20% (50% area, 40% fol. proj. cover)
Proportion of Total Ground Cover (combined %, including seagrass, oysters,aerial roots)	16% (Tattler)	no upper limit to 90% measured (but see Appendix III Sect.2 (26): Cover by Structures)
Substrate: **Texture Class** (Sand to Silty Clay Loam)	* Loamy Sand Sandy Loam for Tattler, Greenshank	no fine-sediment limit to finest encountered (Silty Clay Loam)
Surface Hardness (kg/cm^2)	no lower limit to hardness(softness): softest measured= -0.19	*5.0
Microrelief (roughness) (variance in $(mm)^2$)This is not the range, but a measure of variability of the range over a set distance	no lower (smooth) limit	*1 000$(mm)^2$ variance
Elevation Profile: **Proportion Dry at Low Tide (%)** (see also levels in Fig.2.9)	no lower limit	76% (Godwit)
Wet	34% (Greenshank)	no upper limit to 80% measured
Shallow (<50mm)	no lower limit	*45% (Tattler), no upper limit to 75% measured for other species
50-150mm deep	no lower limit	*50 %
Water: **Mean Salinity over tide cycle (g/l)**	16g/L (Curlew); *6.5 g/L for other species	seawater (up to about 37 g/L)
Secchi transparency of water (m) (natural sediment)	minimum measured: 0.35 m	1.7m (Whimbrel, Greenshank) no upper limit for other species
Orthophosphate levels (mg/L) (see note on consistency of measurement in Appendix II: Orthophosphate)	0.22 mg/L(Greenshank); no lower limit to measurable quantities (0.00 mg/l)	maximum level measured: 1.5 mg/L
Wave height at shore (regular occurrence)	no lower limit	60 mm

are not statistically verified, but are offered as guides until more information becomes available.

Disturbance Buffer Distances

Minimum buffer distances are offered for each common species (Table 2.20). Disturbance distance has been defined as the distance at which a bird is disturbed from feeding. Buffer distances need to be greater, of course, to avoid disturbance. Because disturbance distances vary with the nature of the disturbance, two categories - high key disturbance and low key disturbance - are used to provide appropriate buffers for different human activities. Disturbance from raptores was not included. High key disturbances were:

Table 2.20

Mean disturbance distances and recommended minimum buffer distances for feeding migratory shorebirds. High and Low key disturbances are defined in the text.

Species	Disturbance Distance (metres): High Key	Disturbance Distance (metres): Low Key	Recommended Minimum Buffer Distance in metres
Bar-tailed Godwit	68m +/- 28m n=12	25m +/- 7m n=8	High: 110m Low: 40m
Whimbrel	125m n=2 (100m, 150m)	47m n=3(50m,60m,30m)	High: 160m Low: 70m
Eastern Curlew	103m +/- 24m n=13	47m +/- 23m n=6	High: 140m Low: 80m
Greenshank	Insufficient data	42m +/- 10m n=6	High: N/A Low: 60m
Tattler	Insufficient data	65m n=2(100m,30m)	High: N/A Low: 110m
Pacific Golden Plover	n=1(160m)	n=1 (80m)*	High: 170m Low: 90m
Red-necked Stint	Insufficient data	27m +/- 10m n=3(30m,20m,30m)	High: N/A Low: 50m
Curlew Sandpiper	65m n=2(30m, 100m)	n=1(40m)*	High: 110m Low: 50m

* These values determined by the observer, all others were derived from observations independent of the observer.
N/A = not assessed.

- boats (including their wash): high speed (over 4 knots), noisy, particularly boats navigated close to feeding areas at speed;
- active people: swimming, running, playing, horseriding, shouting, walking purposefully, bait collecting (walking purposefully);
- helicopters, jetskis and other fast, noisy machines.

Low key disturbances were:

- boats: passing slowly (less than 4 knots), wash over 60mm high at the shore, drifting, moored;
- inactive people: fishing, strolling, oysterfarmers working on racks (not walking purposefully);
- dogs: although a major source of disturbance because they chase birds, actual distances are in this category. (Impacts of dogs on birds are discussed in Phillipps (1992)).

Within each category a mean distance and a range are given (90% confidence limit or observed range - see Methods). To allow for the inherant variation in disturbance distances (caused by circumstances, frequency of disturbance or the sensitivity of individual birds), the recommended minimum buffer distance is calculated from the upper range limit, plus 10 metres. These distances might also be used for management of roost sites (see Chapter 6).

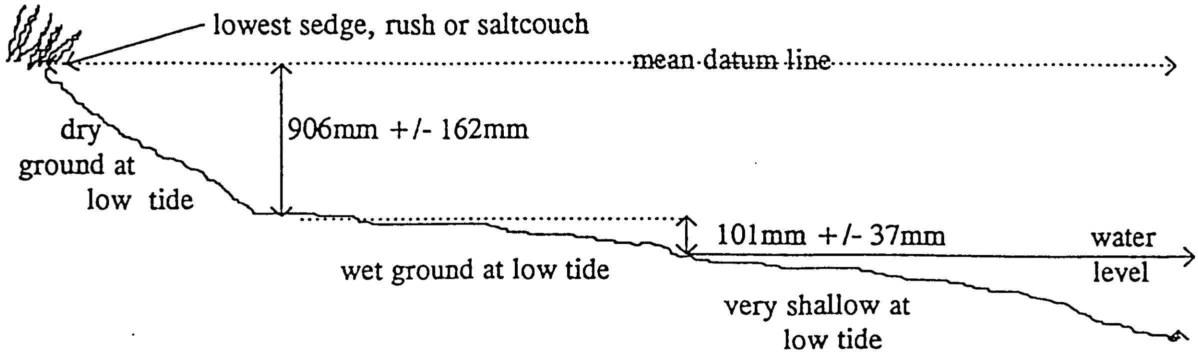
Elevation Profile Levels

Figure 2.9 gives approximate levels for construction of intertidal feeding habitat with the elevation profile level (wetness) characteristics identified in the research. These are for use on intertidal areas of natural tidal regime (see Appendix III Section 3: A1, A6, A10). Levels (distances below an imaginary line at datum height) are based on a 'biological mean datum' (shoreline vegetation) which is roughly constant from estuary to estuary, and is detailed in Appendix II: Elevation Profile.

The difference in height between the dry/wet interface and the wet/shallow interface (that is, the range of heights above water level in which ground remains soggy) is independent of datum and tide, so can be used in other areas (eg. peripheral wetlands). It is influenced by very sandy (drier) or very fine-textured (wetter) soils (the normal texture class being "light sandy clay loam"). All levels are means over the sample of 13 measured flats and are approximations, given with 95% confidence intervals (19 out of 20 chance of

Figure 2. 9

Guide levels for construction and restoration of shorebird feeding habitat at the normal intertidal flat level in estuaries. (Not to scale.)



containing the correct mean). A further area providing shallow water (100mm to 300mm lower) should be included, for very low (spring) tide levels.

Mangrove grew from the shoreline (0mm) to 1 570mm below the data on the sampled flats, with a mean height from lowest mangrove to mean datum of 1 083mm +/- 174mm. Ground below this level is unlikely to support well-established mangrove. These guide levels are intended as first approximations - the levels can be adjusted by visual estimation of % wet etc. on mean low tides (0.3-0.6m at Middle Head) during construction.

General Discussion

The Guide Values

The concept and nature of the guide values is explained in the Introduction and Methods, and summarised in *Using the Guide Values*, below; their development is discussed in Results & Discussion. This section discusses the actual guide values and their implications in estuarine management, and compares them to other published findings where possible. Management strategies for shorebird habitat in estuaries are discussed in Appendix III.

Area Attributes

The Area of the flat was only relevant to Bar-tailed Godwit (main guide values) and Eastern Curlew (supplementary guide values). The minimum guide value's lower limit for Eastern Curlew was just one hectare. Other species were found in any number on flats of any size, and the area of the habitat complex was more important.

This implies that even small flats are potentially important shorebird feeding sites and should not be disregarded on the basis of their small size. However, larger numbers of Bar-tailed Godwits tended to favour larger continuous feeding areas. The large areas for Godwit (minimum guide value of 10.5 ha*, preferable aim value of 21 ha or larger) are driven by the higher numbers of Godwit used in the classes compared to other species, a product of their abundance. But in the context of their generally high population levels, large feeding areas are needed, and reductions in intertidal flat size could render the remaining area of diminished value to flocks of Bar-tailed Godwit (Wiersma & Piersma 1994), because the area becomes smaller than that which is "worth feeding on" by a flock. Clark *et al.* (1993), in a post-mortum of a catastrophic shorebird die-off, noted that intertidal flat loss is most often from landward, removing the areas that remain available for foraging on neap tides. When this loss of area was combined with a second stress duing neap tides - cold weather in their south-east England study - large numbers of shorebirds of many species died.

Area of surrounding habitat (within 1km), excluding the sampled flat area, measures the size of the habitat complex independently of the size of the study flat. It related strongly to species number, so flats small or large may be used by many species if they are part of a greater area of habitat. Pacific Golden Plover numbers in the modelled sample also related to this, though not in the tested sample. Main guide values are given for species number (26 ha minimum to manage for 3+ species) and Pacific Golden Plover (45 ha, preferably 64 ha or more). Supplementary guide values are provided for Eastern Curlew and Whimbrel. In the three species concerned, low suitability was defined by zero birds, and suitable habitat by the occurrence of one bird.

Habitat complexes extending over tens of hectares appear important for sustaining even low population densities of these species. Where habitat was fragmented, the species tended to be absent. Species number had a similar dependence on the extent of the habitat

* confidence intervals are omitted in the discussion for simplicity.

complex (a well documented phenomenon with shorebirds eg. Dann 1994; Pratter 1981; Skagun & Knopf 1994). Beyond direct habitat loss, the fragmentation of habitat complexes may compromise shorebird populations and species diversity on the remaining fragments. Temple & Wolcox (1986) describe habitat fragmentation as not just loss of habitat *per se*, but "an insidious process" affecting size, shape, proximity and spatial arrangement, citing a newly created island in a dam which lost 30% of its original fauna. Management needs to consider small scale fragmentation as well as the larger landscape scales (Laudenslayer 1986).

Total habitat area (within 1km) is a combined measure which may reflect the influence of either of the aspects above, or an interaction between them. It provided fairly large main guide values for Eastern Curlew (minimum of 19 ha, 52 ha or more for "high suitability" habitat). Congdon & Catterall (1994) suggested that curlew territories need to be big enough to provide adequate foraging space on even the highest neap tides. Rogers (1995), after analysing biometric data which showed the population structure of Eastern Curlew, cautioned that merely protecting the area with the most curlews would be insufficient if many feeding areas are necessary to support both sexes and different age classes of the population. Total habitat area is a useful attribute to integrate habitat extent for several species and species number, falling in the range of 31 - 45 ha for minimums, and 49 to 67 ha or more for habitat of high suitability.

Vegetation Attributes

The percentage of surrounding mangroves (on all surrounding shores) was strongly related to numbers of Whimbrel, Greenshank and shorebird species, so main guide values were given ranging from 28-84% minimums and 57-98% or more (Greenshank) for very suitable habitat. Mangroves are part of the environment shown to be favoured by shorebirds in the estuaries - that is, sheltered shores with high sediment regimes (Chapter 1). They may be merely co-habitants of suitable shorebird habitat, but it is likely that their litter fall contributes to shorebird food resources (Chapter 5, Chapter 1 Discussion) and their stabilising function creates suitable substrates (Sato 1984; Mead & Beckett 1990; Clarke & Myerscough 1993; McKee 1993). They also provide shelter and roosts (Ch. 6).

Loss of fringing mangroves may not result in sudden depletion of shorebird populations on an intertidal flat, but it is likely to result in longer term decline. The long term consequences of mangrove loss on fish ecology is well accepted (eg. Pollard 1976, 1981: Burchmore *et al.* 1993). This study implies that mangrove preservation, and provision

(Pulver 1976; SPCC/NSW Fisheries, undated), is also important in shorebird management. AWB (1983) also observed a strong link between shorebird numbers and mangrove fringing in Peninsular Malaysia. The principle includes other littoral trees, such as *Casaurina* in less saline water regimes (Midgely *et al.* 1983).

Adjoining mangrove appeared to have a direct function as shelter and feeding habitat for Tattler in estuaries, as well as any contribution to the trophic web. It is likely Tattler were responding directly to the presence of adjoining mangrove (and ground cover) as an important physical feature of Tattler habitat, or as an indicator of good places to forage. Seagrass seemed to act as a similar direct cue in Moreton Bay (Thompson 1991, 1993). The minimum guide value for adjoining mangrove was 32% (based on occurrence of one Tattler) and the preferable aim value (based on 3+ Tattler) was 55% or more.

Total ground cover (any combination of seagrass, oysters, oyster structures, rocks, mangrove seedlings, bushes and pneumatophores) positively related to Tattler presence, giving a minimum guide value of 27% and preferable aim values of 56% or more. **Mangrove cover** was relevant to Tattler and Greenshank management, but values were low: minimums of 4%, and high suitability values of 13% (Tattler) and 9% (Greenshank), but with very wide confidence intervals. They imply that some mangrove cover is prefered, but there was only a weak suggestion that more cover was better for these species (and only to the measured maximum of 20%). There was no relationship - positive or negative - with other species.

Mangrove cover beyond that encountered on the study flats could be expected to displace feeding area and limit visibility for some species. This has been documented for salt couch *Spartina* (Lane 1992). On the other hand, mangrove cover below 10% is unlikely to compromise any feeding habitat. Implementation of the ground cover guide values above about 10% may create a conflict of management goals between Tattler and other species, needing consideration of management priorities (see *Using the Guide Values*, below). Mangrove colonisation is active in many estuaries where flats have accreted from increased sedimentation (Dunstan 1990). Between 1961 and 1987 Lake Macquarie, for example, lost 50% of its saltmarsh through development and mangrove colonisation, and 18% of its seagrass (through dredging, reclamation, siltation and nutrient enrichment) but gained a 242% increase in mangrove, which colonised both mudflat and saltmarsh (Winning 1990). Long term weather patterns may cause increases in mangrove cover, only to then decline again, as described by Buckney (1987) in the Kooragang Island saltmarsh, Hunter estuary.

Elevation Attributes

Flats are not really flat - different areas have different heights, which are exposed for different durations in the tide cycle, and are either dry, soggy or shallowly covered at low tide. Each category needs to be considered, bearing in mind that these recommendations apply on the bottom third of the tide cycle. If neap or half tide habitat is important on the site in question (if birds congregate early or leave late) management decisions regarding elevation should be modified accordingly. Foreshore developments often remove the upper half tide areas, so past and potential loss of this habitat needs to be taken into account.

The proportion of **dry ground** at low tide was negatively related to Bar-tailed Godwit (though not in the testing sample), Whimbrel and Greenshank numbers. That is, they were more abundant on ground which was *not* dry. Bar-tailed Godwit were assigned guide values of 61% maximum area of dry ground, and preferably 16% or less. In practice, this will relate to the size of the flat - small flats may need smaller proportions of dry ground to remain viable. Whimbrel and Greenshank guide values were supplementary, but even less: the Greenshank maximum was 19%, with a preferable aim value of only 3% or less dry ground at low tide.

The proportion of **wet ground** and **shallow water** (<50mm deep) were positively related to shorebird numbers (more was better). Values for Greenshank were 44% minimum wet ground and preferably ('high suitability') 67% or more. Species number (significant in the modelled sample but not in the testing sample) indicated 50% or more shallow water area. Dry ground on lower stages of the tide appear less useful to some feeding shorebirds than soggy or shallowly covered ground. This relates to prey abundance and/or availability to the birds (depth, activity and hence visibility, ease of probing etc., as discussed in Chapter 5). The amount of soil saturation affects soil-oxygen levels for infauna, and the "workability" of the substrate for both prey and shorebird (Whitten *et al.* 1988b - see Chapter 1 Discussion: *Shorebird Use of the Estuarine Environment*). Tulp & de Goeij (1994) found that the 10% of their study flat in northwest Australia exposed on neap tides was less rich in benthic fauna, and Rehfisch (1994), working in artificial wetlands, found prey could be maximised by manipulation of waterlevel to provide wet and shallow ground. Sampath & Krishnamurthy (1989) found that the presence of shallow water was the main determinant of feeding shorebird densities in their Indian saltponds.

Estuaries can be dynamic, and changes to bottom or shoreline shape can result in unexpected effects. The construction of Port Botany altered tidal currents in Botany Bay, resulting in the erosion of Towra Point (a Ramsar wetland) and the loss of seagrass and its productivity (Butlin 1976). Following ineffectual dredging of the Tweed mouth, a study found that the estuary accumulated 93 000m³ of marine sediment and 5 000m³ of alluvium in one year alone (Druery & Curedale 1979). More insidiously, Dunston (1990) points to extensive sedimentation of estuaries in the Sydney region since early historic records, due to catchment clearance.

Impacts on elevation profile which increase the area of high and dry ground at low tide will degrade shorebird feeding habitat. Impacts which decrease elevation beyond shorebird feeding depth (100 to 150mm deep for the longer legged birds, less for smaller species) remove habitat. There is, however, a need for some higher ground locally for staging and early feeding (as noted above). On flats of high conservation value to shorebirds, elevation profile is a critical attribute of habitat to manage and protect.

Water Attributes

Secchi transparency (visibility) is an inverse measure of sediment load, and reflected an aspect of the sediment-rich environment identified in Chapter 1. Natural sediments maintain flats, and contain nutrients and organic matter which support shorebird prey. Flats in waters with more fine sediments (higher turbidity) had more fringing mangrove and lower elevation profiles. The measure related to Whimbrel, Greenshank and species number (more birds where there were high sediment loads, less near clear water), but it was correlated with other variables so was assigned supplementary guide values. All three were similar: maximum Secchi measures of 1.0 - 1.3 metres visibility, preferable aim values of 0.6 metres or less to the measured minimum of 0.35 m.

These guide values need to be used intelligently, because all turbidity is not good. The guide values refer to the maintenance of regimes of natural turbidity rather than increases in sediments which are either nutrient-poor, organic matter-poor, excessively nutrient rich or harmful in content (such as toxins, pH levels, oxygen content). These may reduce invertebrate prey abundance, promote toxic or excessive algae, alter elevation profiles, smother vegetation, poison the birds directly or degrade the intertidal environment in other ways (Rhyther & Dunstan 1971; Hart 1974; Duery & Curedale 1979; Cullen 1986; Underwood 1989; Barmuta 1990; Hillman *et al.* 1990).

Even changes in turbidity within these guide values, for shorebird habitat conservation, may degrade other natural values in an estuary. Seagrass beds grow in clear waters in which light can penetrate and so are affected by high levels of turbidity (Whitton *et al.* 1988a; Moriarty & Boon 1989). Estuarine management needs to protect all conservation values in an estuary, and actions based on conserving one aspect at the expense of another need careful consideration of ecological impacts and conservation priorities (Lumm 1978; Laubhan & Frederikson 1993; Caughley & Sinclair 1994). Nevertheless, natural fine-sediment regimes are a feature of estuaries with alluvial flats (Bird 1968) and are integral to the creation of good feeding habitat for many shorebirds.

Mean salinity (over the tide cycle) summarised the water salinity regime over the sampled flats. Eastern Curlew numbers were higher on saline intertidal flats than flats with more brackish regimes. The guide values (minimum of 22 g/l; 35 g/l for high suitability) imply that salinity regimes from nearly constant seawater (about 37 g/l) to water of roughly equal parts fresh and sea (in volume or time over the tidal cycle), are acceptable. Eastern Curlew prey - ghost shrimps (*Callianassa* sp.) and small crabs (Dann 1987) - may be less abundant in less saline regimes. Salinity is commonly affected by tidal restrictions, so general estuary management guidelines (Burchmore *et al.* 1993) aimed at managing tidal restrictions will help manage salinity regimes.

Numbers of the other common shorebird species did not relate strongly or at all to the range of salinities measured in the study. Most shorebirds appear flexible, preferring the salinity which maximises prey densities where they are feeding. Salinities of 7-10 g/l for coastal lagoons (Burgess & Hirons 1990) to 1.5 times seawater (Bamford 1983) have been reported as preferred by shorebirds in different places. However, alteration of salinity regimes beyond the natural range can have important affects on infauna and vegetation in tidal wetlands (Klebovich 1968; King & Barclay 1986) (see Appendix III). Note that the salinity values given are the mean over the tide cycle and do not specify the range, tidal or longer term, which can also affect infauna.

Orthophosphate level was measured as a crude indication of nutrient regime over the flats, and is another example of an attribute which can only be given guide values up to the maximum level measured in the study. While reductions in nutrient levels need management, the most common management problem is excessive nutrients from disturbed or enriched catchments (eg. Hillman *et al.* 1990; McComb & Lukatelich 1986), or sewage outfalls (Thompson 1993) overloading the estuarine ecosystem. Urban stormwater management guidelines (EPA, undated) can help with this management.

Greenshank numbers increased with orthophosphate levels (other species were linked to indirect indications of nutrient levels (Chapter 1)), but no values were excessive (Hart 1974; Axelrad *et al.* 1981; Cosser 1989). Guide values for Greenshank (minimum 0.38 mg/l, aim value for high suitability of 0.59 mg/l, to the measured maximum of 1.5 mg/l (Table 1.1)) could be used if this specific management issue arises, but the techniques for measuring the orthophosphate levels used in this study (Appendix II) will need to be duplicated exactly. In general, application of the other guide values will be more important and practical.

Physical Attributes

The proportion of open water surrounding the flat is a measure of the openness of the flat's position in the estuary. Flats in the main channel have a lot of their perimeter bordered by open water, whereas in bays, coves and inlets they are bounded by more land or mangroves. Works which alter the proportions of water and land around flats may impact shorebirds directly or indirectly. The measure related to Bar-tailed Godwit and Eastern Curlew (more birds on open flats) and Greenshank (more birds on flats in bays and inlets). *Flat position is interrelated with many other attributes of habitat, and strongly* associated with size (see Chapter 1 - *The Estuarine Environment*), so the guide values were supplementary.

Those for Eastern Curlew imply that enclosed flats will be used but open (larger) flats will be used by greater numbers. Bar-tailed Godwit guide values (minimum 46% open water, high suitability 82%) imply a greater use of large open flats by large numbers of godwit. In contrast, Greenshank are opposite to Bar-tailed Godwit in needs, requiring enclosed flats (26% maximum openness; high suitability 11% or less) showing a conflict of habitat needs in the management of this attribute (see *Using the Guide Values*, below).

Perimeter length is a function of size and shape. Study flats with longer shoreline lengths were used by more species, but it was not separated from area. Warnock & Takekawa (1995) were able to discern an increase in mudflat importance with "linear" (foraging areas along the tide line) versus "areal" assessment, concluding the importance of "recognising microhabitats within mudflats". On otherwise high flats, the shoreline zone usually contains the wet and shallow elevations favoured by feeding shorebirds. Via both area and elevation factors, impacts which reduce shoreline length may reduce shorebird feeding habitat. Generally, use of the area and elevation guide values will manage this, but flats subject to deposition and erosion, or development on their sides, may have their perimeter length reduced without overall loss of area. The guide value for species number (1 990 metres or more) can be used as a benchmark for judging impacts and designing shapes to support species diversity.

Surface hardness (and surface texture - sandy soils tend to be firmer on intertidal flats) showed no strong relationships with shorebird numbers on the study flats, although most shorebird species tended to avoid pure sand. Extreme hardness would limit probing shorebirds. Substrate qualities are likely to impact shorebirds via prey abundance, species, and availability (Quammen 1982; Gerritsen & van Heezik 1985). They need to remain within the range naturally occurring on intertidal flats, and changes in substrate should be avoided on flats of high conservation value to shorebirds, to ensure conservation of invertebrate populations.

The relationship of surface hardness to Pacific Golden Plover numbers was weak and not significant at the adjusted significance level, but a guide value is given (maximum hardness of 1.17 kg/cm^2 (see Appendix II for measuring technique)) which gives a conservative guide. Maximum hardness encountered was 5 kg/cm^2 and this is inferred as a natural upper limit (Table 2.19). Actual particle size (soil texture) was not found to be directly related to shorebird habitat preference, although it has been a useful *a priori* classifier of shorebird habitat (eg. Goss-Custard & Yates 1992), particularly where the range of substrate types is much greater than in this study (eg. Smith & Connors 1993, Thompson 1991). Botton *et al.* (1994) found no relationship between shorebird feeding distribution and sediment size in Delaware Bay, U.S.A., but rather density of the eggs of the Horseshoe Crab, an important prey. Goss-Custard *et al.* (1991) found that sediment parameters correlated with Bar-tailed Godwit density in English estuaries, concluding that estuary dynamics (tidal amplitude, wave action) affected sediment, prey and birds.

Disturbance Distances

The disturbance distances and recommended buffer distances (Table 2.20) should be considered interim because of the small sample sizes (Morrison 1988). Distances are not proportional to body size of the species concerned - Bar-tailed godwit, a large species, was the most approachable, and Pacific Golden Plover and Tattler, both medium in relative size, were among the most sensitive to disturbance. Though not part of the study, raptors were observed to cause frequent disturbance, particularly the White-bellied Sea-Eagle

Haliaeetus leucogaster. Cresswell & Whitfield (1994) found that raptores accounted for the most shorebirds deaths in a small estuary near Edinburgh (50% of the population and 90% of juveniles of one species were taken in 2 years, with one Merlin *Falco columbarius* taking 5-19% of all small shorebirds). While normally outside the scope of estuary management, it is worth noting the potential for disturbance and mortality by raptors when they are being managed simultaneously, eg. by provision of nesting towers (Rooney & Assoc. 1994).

Buffer distances varied with species within a range of 110 to 170 metres for high key disturbance, and 40 to 110 metres for low key disturbances. It is not practical to enforce different buffer distances for different species, so general minimum buffer distances on feeding grounds of 100 metres to low key disturbance sources and 170 metres to high key disturbance sources, are suggested. Low and high key disturbance sources are defined in Results and Discussion: *Disturbance Buffer Distances.* Management strategies for feeding areas are suggested in Appendix III; for roosts, in Appendix IV.

These results are substantially greater than the "at least 50m" buffer suggested by Helmers (1993) for prairie wetlands. Burger & Gochfield (1991) found an effect from people within 100m on the time spent foraging by small shorebirds, as well as an increase in nocturnal foraging when daytime disturbance was high. This and the observations in this study indicate that casual assessment of disturbance distances (usually the putting up of a flock) does not take subtle effects into account. Pomerantz *et al.* (1988) suggested categories for disturbance effect which reflect more subtle impacts than could be discerned in this study: indirect mortality, lowered productivity, reduced use of the site, reduced use of preferred habitat within the site, aberrant behaviour and stress. Underwood & Kenelly (1990), in a survey of disturbance to the littoral zone on Sydney foreshores, found that human activity was affected by weather (sunny or overcast), tide height, time of day and holidays. Straw (1994) records jet skiers having a significant effect on feeding and roosting waders, and reports, as a useful precedent, an application to council for jet skiing on the Clarence River which was rejected on the grounds of its impact to shorebirds.

Testing the Guide Values

Comparing the regression lines used for the guide values with those of a second independent sample is not a definitive test of the guide values, but it does provide a better insight into their ability to reflect real relationships, than just the confidence intervals. Nine of the 11 main relationships used in the models were also present in the second sample (Table 2.21) - a success rate of 82% which compares favourably with published modelling benchmarks (Hurley 1986; Morrison *et al.* 1987; Diefenbach & Owen 1989; also discussion in Chalk 1986). The others (Bar-tailed Godwit:proportion of dry ground at low tide, and Pacific Golden Plover:surrounding area excluding the sample flat - based on a small sample) are retained for "tentative consideration" (Caughley & Sinclair 1994). Neither of the two supplementary relationships tested were present in the second sample, although one (Whimbrel:total area within 1km) was replaced by a very similar relationship (Whimbrel:surrounding area excluding the sample flat).

Table 2.21

Summary of results of model testing.

Shorebird Species	Habitat Attribute	Relationship present in testing sample?
Bar-tailed Godwit	Area of Flat	√
	Proportion of Dry Ground #	×
Whimbrel	Surrounding Mangrove	√
Eastern Curlew	Total Habitat Area $	√
Greenshank	Proportion of Wet Ground #	√ (excluding shallow sites)
	Surrounding Mangrove	√ (including other trees)
Tattler	Adjoining Mangrove	√
Pacific Golden Plover	Area of Surrounding Habitat $	×
Species number (3 or more)	Surrounding Mangrove	√
	Perimeter Length #	√
	Area of Surrounding Habitat $	√

\# at low tide $ within 1km

Using the Guide Values

Concept

In summary, the guide values are mean measurements of relevant habitat features corresponding to low numbers of birds and an arbitrary threshhold "high" number of birds, all derived from the sample (see Methods). They are presented as minimum "guide ranges" because ranges are more appropriate than single values in ecological relationships and the variable estuarine environment. These guide ranges are "ball-park" targets to aim for in estuary land management to avoid affecting shorebird populations adversely.

Each attribute of habitat, for a species, has three guide values to use as limits of change:

- a "High Suitability" guide value range to be used as a minimum wherever possible, or where shorebird conservation is a priority. Values below this range are unacceptable under these circumstances, and values above these minimums are preferable.
- A lower guide value range ("Suitable") to aim for as a general minimum acceptable level for areas of lower priority for shorebird conservation; and
- an absolute minimum value (lowest range limit) below which reduction of the habitat attribute is unacceptable under any circumstances.

These values provide managers with guidance for a range of circumstances and their application needs knowledge of conservation priorities and the conservation value of the site (see Hurley 1986; Salwasser 1986). This approach may seem complex, but further simplification (combining species, or reducing guide values to a single figure) would make them too general, making excessively gross assumptions about estuarine ecosystems, reducing accuracy, and limiting their flexibility for use in complex issues.

The tables (eg. Table 2.2) have main and supplementary attributes of habitat. The main entries (above the dotted lines) are for those most strongly linked with bird numbers and imply the important attributes for each species. Supplementary entries (below the dotted lines) are those which were also related to bird numbers but were not separable from the main attributes, or were related more weakly. These supplementary guide values can be used with these attributes in particular, bearing in mind that their importance for the species concerned is likely, but not fully determined.

Spirit of use

The guide values should be used in the spirit in which they are intended - that is, as "ball-park" values which provide an insight into probable habitat needs, used in conjunction with local and regional considerations, site specific information, ecological principles, and common sense, for the *conscientious* maintenance of shorebird populations.

The 'habitat unit' used in the study, and in the guide values, is the *individual intertidal flat*, and the guide values must be used at this scale. Also, the numbers of birds used in the habitat suitability classes must be borne in mind. The guide values are for use on any "ordinary" piece of intertidal land - when shorebird populations on a flat exceed the highest class boundary, the minimum values in the models will no longer be sufficient for good management. It is suggested that if this is the case, or if priority species are present (Table 3.8), shorebird conservation should be a very high management priority for the site, all aspects of the habitat should be fully protected, and certainly no reductions made in the attributes identified. See also *Misuse*, below.

Applications

The guide values can be used for:

- environmental impact assessment (conducting an E.I.S. or assessing a development application and its E.I.S.);
- management of estuaries and protected areas, including preparation of strategic and management plans; and
- construction and enhancement of shorebird feeding habitat.

Environmental Impact Assessment

Assessments fall into two categories: assessment of the potential effects of the development on shorebird habitat, helped by the models in this chapter; and assessment of the importance (conservation value) of the affected site to shorebirds. Chapter 3 provides help with this assessment. The importance of the habitat to shorebirds will affect the assessment of the development's impact on it, so the assessments need to be done together.

Impacts on shorebird habitat need to be identified (Mann 1978). See Appendix III for a matrix of land/resource-use actions and relevant "impacts" (Section 1), descriptions of impacts related to the attributes of habitat identified in the study (Section 2), and suggested management strategies (Section 3). Assessment then has to define what needs to be preserved to avoid degrading the habitat. (This is distinct from actual detection of environmental impact, which requires a different approach to that used in this research. See, for example, Bradbury *et al.* (1984), Lincoln Smith (1991), Goss-Custard & Yates (1992), Underwood (1991). The guide values can provide minimum benchmark levels of important attributes of habitat which need to be maintained, for common species and species number known to use the site (through field observation), or likely to use the site (determined by, for example, the Chapter 3 models). Keough & Quinn (1991) recommend avoiding the use of species number or abstractions such as "species richness", because they may not detect impacts clearly affecting individual species.

The most appropriate of the three guide values will need to be selected, based on shorebird use (species and number) and conservation priority, to prevent the habitat from being degraded for shorebird conservation. Information on projected levels of change caused by the development or resource use will be needed.

Management of Estuaries and Protected Areas

There is currently no comprehensive network of protected areas for migratory shorebird conservation in the estuaries (see Smith 1991; Ray & McCormick-Ray 1992; Watkins 1993; Watkins 1995), although there is shorebird habitat in national parks, marine parks, nature reserves, fish habitat reserves, aquatic reserves and designated areas under local government environmental plans, all of which need sound management. Shorebirds in estuaries are so specific in habitat needs, and estuaries are such restricted habitats under such pressure from land and resource use, that the management of all southern east coast estuarine habitat should include shorebird needs. Such management requires:

- identification of areas of high conservation value to migratory shorebirds;
- knowledge of which aspects of the estuarine environment are important to shorebirds; and
- management of the important attributes of habitat within limits of acceptable change.

Areas that qualify for high, potentially high or very high conservation value for one or more species, or species number, can be identifed with the help of the keys in Chapter 3, manually or by using the criteria as parameters in G.I.S. based selection (Ferrier & Smith 1990). This can complement existing knowledge (literature reviews eg. Smith 1991, data from bird study groups) and field surveys, or can be used to select areas for more detailed assessment.

Once areas have been identified, the habitat suitability models in this chapter can indicate the important attributes of the habitat to be conserved, for the common species concerned. Species associations (Chapter 1) help to estimate which other species may be involved. Appendix III provides information on which environmental impacts may affect these attributes of habitat, and has suggestions on how to monitor and manage each attribute. Techniques useful for monitoring are given in Appendix II.

The guide values can be used as minimum management criteria - values for "very high habitat suitability" being minimums for high conservation value habitat. As minimums they may be inadequate to maintain habitat which is used by higher shorebird numbers than the numbers used in the class boundaries of the models (see important considerations in *Spirit of use*, above), or for rarer species (see Table 3.8, Chapter 3 Discussion: *Conservation*

Value Classes). Toth & Baglien (1986) warn that models are too imprecise for species at risk, which need direct monitoring. Likewise, management of areas of high conservation value for shorebirds benefits from constant monitoring and from detailed studies of shorebird behaviour and habitat use at the specific sites (Lane 1991, Lincoln Smith 1991). The guidelines provided in this study are a first approximation and should be refined, replaced or added to by future studies.

Construction or Enhancement of Shorebird Feeding Habitat

The important attributes of natural habitat need to be known and simulated to maximise the likelihood of artificial habitat being used (Kusler & Kentula 1990). The guide values which are most likely to support high numbers of shorebirds should be used in the design. The models indicate appropriate attributes of habitat to be incorporated and provide their minimum levels. The keys in Chapter 3 complement this by providing a rapid assessment of the suitability of the proposed site and an assessment of the species of shorebird able to be catered for in the design. For example, if the artificial or enhanced feeding habitat was planned for a small isolated site, it may need to be enlarged, or located in an area where its addition to existing habitat would make the whole area viable (eg. see Wilcox 1986, who reported an increase in use of an entire wetland complex after some habitat addition in California). However, it is important not to "spread the effect" of habitat loss, discussed by Adam (1993) regarding the transplanting of saltmarsh plants to reserves around Botany Bay, and "habitat augmentation" for terns and shorebirds at Towra Point, already a Ramsar wetland, to offset losses caused by airport construction*.

The highest guide values can be minimum target values in the design because more is better with most attributes. There are exceptions to this: (a) the reverse applies with those that adversely affect shorebird habitat suitability (eg. proportion of dry ground at low tide), and (b) there can be "too much of a good thing" (eg. salinity or cover beyond that measured). Upper limits are shown in the models. Further guide values are given for other attributes based on the measured ranges on the sample of natural flats (Table 2.19), disturbance buffer distances to be incorporated (Table 2.20) and elevation levels (Fig. 2.9). Factors which may help in benthos colonisation are discussed in Chapter 5. Peripheral wetlands, including artificial "accidental" wetlands associated with reclamation works, can also be enhanced amd managed for shorebird habitat (see General Conclusions, also Davidson & Evans 1986). Shorebird feeding areas should be provided with a roost: natural

* Another problem with loss mitigation through habitat creation, beside the fact that contructed areas are usually much smaller than the areas lost, is one of time. They are typically started after the completion of an EIS which was initiated through findings of the development's EIA. Construction therefore lags well behind habitat loss, and then benthic fauna may need 3 years (Wilcox 1986) to 5 years or more (Saenger *et al.* 1989) to become stabilised.

roosts are characterised in Chapter 6; guidelines for roost construction are given in Appendix IV.

Misuse

The guide values are open to misuse, even mischievous misuse, if taken out of the context of their intended use. Some precautions are:

Extrapolation of values: There is no justification in projecting the values of the attributes beyond the ranges measured in the study. Examples discussed above include salinity, turbidity, mangrove cover and orthophosphate (nutrient levels). For example, there are no grounds for claiming that a hypersaline water regime will improve habitat for Eastern Curlew just because the study found that low salinity regimes were less favoured.

Extrapolation of application: The guidelines are only for intertidal estuarine lands, and only for low tide (see Chapter 1: Methods, for the ecological boundaries of the study). The guide values cannot be used to define attributes of other shorebird habitats, even used by the same species. See also *Regional Coverage and Application*, below.

Unnatural attributes: The guide values pertain to attributes of natural habitat. This is most relevant to turbidity as explained above; the guide values are intended for the maintenance of natural sediment regimes, threatened, for example, by increased seawater inflow from channelling (see Appendix III). They cannot be used to justify unnatural sediment inflow to tidal wetlands. The precaution also extends to those for area of surrounding habitat: the areas used must be genuine shorebird feeding habitat of acceptable quality.

Scale: Guide values only apply to discrete individual intertidal flats. Areas, proportions of surrounding mangroves, elevation proportions etc cannot be inflated in value by combining areas bigger than the individual flat unit which is the subject of the assessment or likely impact. Temporal scale is also important: the guide values relate to low tide. At higher stages of both ebbing and making tides, shorebirds use smaller, higher and sometimes more vegetated intertidal areas as staging and early feeding habitat (Dettmann 1989; Driscoll 1993a; also Chapter 6 Introduction: *Shorebird Roosts and their Role in the Tidal Routine*). These sites can have high conservation value to shorebirds at these times.

Using minimums as maximums: Guide values are minimums: they do not represent all that is needed and cannot be used to justify habitat loss. Many of the regression lines imply that more can support more shorebirds, and any loss of the attribute will constitute a decrease in potential as shorebird habitat. Loss or degradation needs to be assessed in the context of the site's local and regional significance, singularly and in combination with other past and potential habitat loss (Driscoll 1993b).

While legislation continues to allow development proponents to prepare their own environmental impact statements, assessors will need to be vigilant against intentional misuse of these guidelines. This is not necessarily restricted to small-time operators. For example, Underwood (1993) found the Federal Airports Corporation, a responsible public office, to have "cavalier disregard" for the E.I.A. process during the Third Runway project, Botany Bay.

Conflicts of interest

Within shorebird management, application of guide values for one species may compromise habitat for other species (eg. total ground cover for Tattler, degree of openness for curlew and Greenshank) (Table 1.16), so management decisions need due consideration of the impact. Within overall estuary management, application of guide values may compromise other estuarine values (eg. maintenance of sediment regime may decrease likelihood of seagrass colonisation). In the maintenance of natural habitat, most conservation managers and agencies are of the philosophical position that they should maintain the natural *status quo* while minimising human impact (Thompson 1993). Conflicts are more likely in impact management, and construction or modification of habitat. Managers will need to balance the various estuarine values of a site according to local and regional significances.

Managing wetlands for multiple goals, eg. multiple species or groups of organisms (Integrated Wetland Management) is discussed in the context of shorebird habitat management by Laubhan & Fredrickson (1993). Beside widely acknowledged goals, such as fishery management (which is nevertheless still compromised by developments despite strict controls (Blumer 1993; Leadbitter & McDonall 1993)), there are many which receive little attention: Bell & Edwards (1980), for example, document many New South Wales estuarine sites of significance to aboriginal people, and Pressey & Griffith (1987) mention rare butterflies confined to mangroves and note that one estuary (the Tweed) has a thoroughly unique community of mangrove tree species.

Regional coverage and application

The data from which the guide values have been developed were collected in New South Wales estuaries. Although the state borders are political, they also approximately define a section of the Australian coast with discrete, relatively small estuaries and coastal lagoons. North and south of the New South Wales borders sheltered coastal landforms change, forming larger, more open complexes of intertidal habitat. Conclusions drawn from this data will not be fully applicable to these different landforms. Also, shorebird populations differ in species composition and size outside the region. Knots and small plover, for example, form a greater proportion of the population in North Queensland (Garnett 1983; Pell & Lawler 1996). There is no validity in extrapolating beyond the study region.

However, in the absence of equivalent data it may be attempted (eg. Appendix V: *Example of Use of Assessment Keys*). The most likely extrapolation will be to Moreton Bay, adjacent to the study area's northern limit, and a region with internationally important shorebird populations (Thompson 1990, Watkins 1993) and intense pressure on shorebird habitat from coastal development (Driscoll 1993a, Geering & Driscoll 1994). Some general principles from this research are likely to remain valid in Moreton Bay, such as the importance of avoiding habitat fragmentation. But application of the guide values cannot be recommended because shorebird populations and habitat units will be different to those used to define the habitat suitability classes. If used, they should only be applied to estuaries and small estuarine-like systems within the Bay, not to the open waterbody or its shores. Different habitats are available in Moreton Bay, and shorebirds use the habitats differently (Thompson 1991; Congdon & Catterall 1994).

Conditions north of Great Sandy Strait (Driscoll 1995) and on the southern coast (Dann 1994) are too different for the guide values to be used directly, though some principles, interpreted with local knowledge, may be useful in the more discrete estuarine wetlands. Even within the study area, there are coastal shorebird habitats not covered in this research: reefs, beaches, saline or brackish peripheral wetlands, floodplain wetlands. Applying guide values outside the environment in which they were developed will take them out of context, and is likely to be counter-productive. Long term changes may occur in shorebird populations, requiring revision of the habitat suitability class criteria used in the models.

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