Lawler, W. (1996) Guidelines for management of migratory shorebird habitat in southern east coast estuaries. Unpubl. M.Res.Sc. thesis, University of New England, Armidale.

Appendix III

Estuarine Management for Shorebirds

This appendix contains general advice for management of migratory shorebird habitat in estuaries. It is extracted from Lawler (1994)[1], a draft management manual prepared from the research findings and other sources, and is included to increase the usefulness of the thesis for shorebird habitat management. It complements the research by suggesting ways to manage the issues addressed in the research, and raised by it.

The appendix is in three sections:

Section 1 is a matrix of causes and effects of management issues, useful in identifying impacts of land use and therefore management strategies needed to conserve shorebird habitat;

Section 2 considers the impacts so identified, which bear on the habitat attributes identified as important in the research; and

Section 3 suggests appropriate management strategies, drawn from the conclusions from the research and wider sources in literature and discussions with managers. A bibliography (*Further Reading*) lists published information either drawn upon for the appendix or useful for more detailed investigation.

[1]Lawler, W. (1994) *Draft Management Manual for Migratory Shorebird Feeding Habitat in New South Wales Estuaries*. National Parks & Wildlife Service (N.S.W.).

Section 1: Identifying the Problem

There are many human activities which can potentially affect the feeding habitat of shorebirds, but a smaller number of actual effects. Activities which may adversely affect shorebird habitat - developments, land and resource use and recreation - are here called 'threats'. The effects of these threats on the important attributes of intertidal habitat are called 'impacts'. By directing assessments to the impacts, one focuses on the fewer, more relevant and more manageable issues.

The matrix of threats and impacts which forms this section (Table III.1) gives many examples of 'threats' (vertical list) and 'impacts' (horizontal list). You will probably encounter other threats, but they will most likely cause a subset of the listed impacts. Most of the impacts relate to the important habitat attributes described in the research (some impact birds directly).

The matrix is a combination of small and large scale effects, and short and long term effects. This may cause apparent contradictions. For example, dredging may cause high turbidity while excavating (short term) but afterwards lower turbidity on the high tide by allowing greater inflow of seawater. Construction of a groyne may cover intertidal areas (local scale), but may cause changes to currents which result in deposition of additional areas elsewhere.

Other contradictions depend on circumstances: a floodgate or wall will increase salinity upstream if there is no freshwater inflow, but will decrease salinity if there is a freshwater catchment. Local knowledge and environmental impact studies are required to assess the impacts on the environment from activities and proposals.

To use Table III.1, identify your threat in the alphabetical vertical list, then look along the relevant row. Ticked columns on the row correspond to possible impacts. The impacts are described, and linked to relevant habitat attributes, in Section 2, by numbers. Criteria for important habitat attributes are in Chapters 2,3 and 6 of the thesis, and suggested management strategies for each impact on the habitat attributes are in Section 3 of this Appendix.

Table III.1

Matrix of 'threats' and 'impacts' on migratory shorebird (wader) intertidal feeding habitat in estuaries. Use this matrix to help identify possible impacts on important habitat attributes from existing or proposed land and resource use, and diffuse problems. See text (this Section) for explanation; see Section 2 for information on each impact and Section 3 for some suggested management strategies. The attributes used are based on the research in Chapter 1; guidelines for management of the habitat attributes are in Chapter 2.

THREATS \ IMPACTS	1 direct intertidal flat loss	2 habitat fragmentation	3 mangrove loss	4 seagrass loss	5 loss of fringing veg.	6 erosion	6 deposition	7 decreased soil texture (mud)	7 increased soil texture (sand)	7 changes to soil texture	8 increased elevation	8 decreased elevation	8 changed profile	9 changed shape or position	9 reduced shoreline length	10 increased area	11 increased roughness	11 decreased roughness	12 disturbance by humans	12 disturbance by dogs	12 disturbance by waves	12 disturbance by noise	12 disturbance by sight	13 increased salinity	13 decreased salinity	14 decreased invertebrates	14 changes to invertebr. species	14 decreased invertebr. diversity	15 changes to tidal regime	16 changes to wave climate	16 increased wave action	17 changes to soil pH	17 changes to water pH	18 increased nutrients	19 decreased dissolved oxygen	20 toxicity - heavy metals	20 toxicity - chemical	20 toxicity - oils	20 toxicity - algal/disease	21 increased hydrogen sulphide	22 increased organic matter	22 decreased organic matter	18 decreased nutrients	23 decreased turbidity	23 increased turbidity	24 increased algae	25 increased mangrove cover	25 changed vegetation cover	26 increased cover - structures	27 increased water level	27 decreased water level	THREATS
agricultural development					✓		✓	✓		✓	✓		✓	✓			✓								✓		✓		✓	✓		✓	✓	✓		✓		✓		✓	✓	✓			✓	✓						agricultural development
agricultural runoff							✓			✓	✓		✓	✓	✓	✓		✓							✓		✓					✓	✓	✓		✓		✓		✓	✓	✓			✓	✓	✓	✓				agricultural runoff
aircraft																						✓	✓																													aircraft
amateur fishing																			✓	✓	✓	✓	✓								✓								✓													amateur fishing
bait collecting																	✓		✓	✓			✓			✓	✓	✓																								bait collecting
bank improvement	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓				✓							✓			✓															✓				✓				bank improvement
barrages	✓	✓	✓	✓			✓	✓		✓	✓		✓	✓				✓						✓	✓	✓	✓	✓	✓	✓														✓		✓	✓	✓	✓	✓	✓	barrages
beachwalking																	✓		✓	✓			✓																													beachwalking
boat wash			✓	✓	✓	✓	✓			✓	✓	✓	✓	✓		✓					✓					✓	✓	✓	✓	✓	✓														✓			✓				boat wash
boating wastes																											✓							✓		✓				✓	✓	✓				✓		✓				boating wastes
buffer loss		✓	✓		✓					✓									✓	✓		✓	✓			✓						✓	✓		✓								✓		✓							buffer loss
burning (catchment)					✓		✓			✓	✓		✓	✓		✓										✓								✓	✓							✓	✓		✓							burning (catchment)
canal developments	✓	✓	✓	✓	✓	✓	✓					✓	✓	✓	✓				✓	✓	✓	✓	✓			✓	✓		✓	✓		✓	✓	✓		✓		✓	✓	✓		✓		✓		✓		✓				canal developments
channelling	✓	✓		✓		✓				✓	✓	✓	✓	✓	✓	✓								✓					✓	✓	✓		✓											✓	✓			✓				channelling
clearing (catchment)			✓			✓	✓			✓	✓		✓	✓		✓		✓	✓				✓			✓	✓	✓					✓	✓	✓							✓	✓		✓			✓				clearing (catchment)
crabbing																			✓		✓	✓	✓																													crabbing
dogs - exercising/unconstrain																			✓	✓			✓																													dogs - exercising/unconstrain
drainage canals	✓	✓	✓	✓	✓		✓			✓	✓	✓	✓	✓	✓	✓									✓		✓		✓			✓	✓	✓		✓					✓	✓			✓	✓		✓			✓	drainage canals
dredging & dumping (spoil)	✓	✓		✓		✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓						✓		✓	✓		✓	✓	✓	✓	✓											✓	✓		✓	✓				dredging & dumping (spoil)
ecotourism																	✓		✓			✓	✓											✓		✓		✓	✓	✓	✓	✓				✓			✓			ecotourism
effluent disposal										✓								✓							✓		✓	✓				✓	✓	✓		✓	✓	✓	✓	✓	✓	✓			✓	✓		✓				effluent disposal
extractive industries	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓			✓		✓	✓						✓						✓		✓	✓	✓			extractive industries
fishing/ prawning/scalloping				✓																	✓	✓	✓			✓	✓	✓			✓														✓			✓				fishing/ prawning/scalloping
floodgates	✓	✓	✓	✓				✓		✓	✓		✓	✓	✓			✓						✓	✓	✓	✓	✓	✓	✓		✓	✓											✓	✓	✓		✓		✓	✓	floodgates
floods	✓					✓	✓	✓		✓	✓	✓	✓	✓		✓		✓							✓		✓		✓	✓				✓								✓			✓		✓	✓		✓		floods
foreshore development	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓				✓	✓		✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓				✓	✓	✓		✓	✓			foreshore development
four-wheel driving			✓		✓	✓	✓						✓	✓			✓		✓	✓		✓	✓			✓			✓										✓						✓			✓				four-wheel driving
grazing					✓	✓	✓										✓		✓	✓														✓		✓				✓	✓	✓			✓	✓		✓				grazing
groynes	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓									✓			✓	✓																✓	✓				groynes
herbicides					✓																																	✓										✓				herbicides
horse-riding					✓	✓											✓		✓	✓			✓																									✓				horse-riding
industrial pollutants			✓	✓	✓			✓										✓								✓	✓	✓				✓	✓	✓		✓	✓	✓	✓		✓	✓			✓	✓		✓		✓		industrial pollutants
industrial waste (bulk)			✓	✓	✓		✓	✓		✓	✓		✓	✓		✓	✓	✓						✓	✓	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓	✓	✓	✓	✓			✓	✓		✓		✓		industrial waste (bulk)
jet-skiing						✓							✓						✓		✓	✓	✓								✓																		✓			jet-skiing
jogging																	✓		✓	✓			✓																									✓				jogging
landfill	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓				✓			✓	✓			✓	✓		✓	✓	✓	✓	✓	✓				✓	✓		✓				landfill

IMPACTS

IMPACTS	landfill	leachates	levee construction	logging (catchment)	low river flows (drought,dams)	maricultural development	mining (catchment)	mooring	netting	nutrient-rich runoff	off-road vehicles	oil spills	organic pollution	oysterfarming
decreased water level			✓											
increased water level			✓											
increased cover - structures						✓		✓						
changed vegetation cover	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
increased mangrove cover			✓	✓			✓			✓			✓	
increased algae	✓	✓	✓							✓			✓	
increased turbidity	✓			✓			✓			✓	✓		✓	
decreased turbidity					✓									
decreased nutrients					✓									
decreased organic matter										✓			✓	
increased organic matter	✓	✓								✓			✓	
increased hydrogen sulphide	✓	✓			✓					✓			✓	
toxicity - algal/disease	✓	✓						✓			✓	✓		
toxicity - oils	✓	✓												
toxicity - chemical	✓	✓					✓							
toxicity - heavy metals	✓	✓								✓			✓	
decreased dissolved oxygen					✓									
increased nutrients	✓	✓				✓				✓			✓	
changes to water pH	✓	✓	✓	✓			✓							
changes to soil pH		✓	✓				✓							
increased wave action														
changes to wave climate	✓		✓		✓	✓								✓
changes to tidal regime	✓		✓		✓						✓			
decreased invertebr. diversity		✓								✓		✓	✓	
changes to invertebr. species		✓	✓	✓		✓	✓		✓	✓		✓	✓	
decreased invertebrates	✓	✓	✓								✓	✓		
decreased salinity			✓	✓										
increased salinity			✓		✓									
disturbance by sight						✓		✓	✓		✓			✓
disturbance by noise	✓		✓			✓			✓		✓			✓
disturbance by waves						✓		✓						
disturbance by dogs											✓			
disturbance by humans	✓		✓			✓		✓	✓		✓			✓
decreased roughness	✓			✓			✓			✓				
increased roughness	✓										✓			
increased area	✓			✓	✓		✓							
reduced shoreline length	✓				✓									
changed shape or position	✓			✓	✓	✓	✓				✓			✓
changed profile	✓		✓	✓	✓	✓	✓				✓			✓
decreased elevation	✓													
increased elevation	✓		✓	✓	✓	✓	✓							✓
changes to soil texture	✓		✓	✓	✓	✓	✓			✓		✓	✓	
increased soil texture (sand)	✓				✓	✓								
decreased soil texture (mud)	✓		✓				✓						✓	
deposition	✓			✓	✓	✓	✓				✓			✓
erosion	✓										✓			
loss of fringing veg.	✓		✓	✓							✓			
seagrass loss	✓	✓					✓	✓				✓		
mangrove loss	✓	✓	✓								✓			
habitat fragmentation	✓		✓		✓	✓								✓
direct intertidal flat loss	✓		✓		✓	✓								✓

IMPACTS	pesticides	pollution	quarrying	recreation	residential development	residential runoff	rockwalls	rubbish dumping / littering	runoff	sailboarding	sandmining	scouring (dredging)	sediment-rich runoff	sedimentation / siltation
decreased water level					✓		✓		✓					✓
increased water level							✓		✓				✓	✓
increased cover - structures				✓	✓		✓	✓						
changed vegetation cover		✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
increased mangrove cover						✓	✓		✓				✓	✓
increased algae		✓		✓	✓	✓	✓	✓	✓					
increased turbidity		✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓
decreased turbidity					✓	✓	✓					✓		
decreased nutrients		✓							✓		✓		✓	✓
decreased organic matter		✓		✓	✓	✓		✓	✓				✓	✓
increased organic matter		✓		✓	✓	✓		✓	✓		✓			
increased hydrogen sulphide		✓		✓	✓	✓		✓	✓					
toxicity - algal/disease		✓	✓	✓	✓	✓		✓	✓		✓			
toxicity - oils	✓	✓		✓	✓	✓		✓	✓					
toxicity - chemical		✓						✓	✓					
toxicity - heavy metals		✓		✓	✓	✓		✓	✓				✓	✓
decreased dissolved oxygen									✓					✓
increased nutrients		✓		✓	✓	✓		✓	✓				✓	✓
changes to water pH		✓	✓		✓				✓		✓		✓	✓
changes to soil pH		✓	✓		✓				✓		✓		✓	✓
increased wave action				✓	✓		✓					✓		
changes to wave climate					✓		✓				✓	✓	✓	✓
changes to tidal regime					✓		✓		✓		✓	✓	✓	✓
decreased invertebr. diversity	✓	✓			✓	✓	✓		✓				✓	✓
changes to invertebr. species	✓	✓			✓	✓	✓		✓		✓		✓	✓
decreased invertebrates	✓	✓	✓		✓	✓	✓		✓		✓		✓	✓
decreased salinity		✓			✓	✓	✓		✓					
increased salinity		✓					✓					✓		
disturbance by sight				✓	✓					✓	✓			
disturbance by noise			✓	✓	✓						✓			
disturbance by waves				✓	✓									
disturbance by dogs				✓	✓					✓				
disturbance by humans			✓	✓	✓			✓		✓	✓			
decreased roughness			✓				✓		✓		✓		✓	✓
increased roughness			✓	✓			✓		✓		✓			
increased area							✓		✓				✓	✓
reduced shoreline length			✓		✓		✓		✓		✓			
changed shape or position			✓	✓	✓	✓	✓		✓		✓	✓	✓	✓
changed profile			✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
decreased elevation			✓		✓		✓		✓		✓	✓		
increased elevation			✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
changes to soil texture		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
increased soil texture (sand)				✓			✓		✓		✓		✓	✓
decreased soil texture (mud)		✓					✓		✓				✓	✓
deposition			✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
erosion			✓		✓		✓		✓		✓	✓		
loss of fringing veg.		✓	✓	✓	✓		✓				✓			
seagrass loss		✓			✓				✓		✓	✓	✓	✓
mangrove loss		✓	✓		✓		✓				✓			✓
habitat fragmentation			✓		✓		✓				✓			
direct intertidal flat loss			✓		✓		✓	✓			✓			

IMPACTS	sewage drifts	sewage outfalls	shooting	shoreline stabilisation	stormwater outfalls	swimming	tidal restrictions	tidegates	trail-bike riding	urban runoff	visitation increase	water-skiing	waterfront structures	wet subdivisions
decreased water level							✓	✓						
increased water level		✓			✓		✓	✓		✓				
increased cover - structures				✓									✓	✓
changed vegetation cover		✓		✓	✓		✓	✓	✓	✓	✓		✓	✓
increased mangrove cover		✓					✓			✓				
increased algae	✓	✓			✓		✓	✓		✓	✓			✓
increased turbidity	✓	✓			✓				✓	✓	✓	✓		✓
decreased turbidity				✓			✓							
decreased nutrients														
decreased organic matter	✓	✓			✓		✓			✓	✓			✓
increased organic matter	✓	✓			✓		✓			✓	✓			✓
increased hydrogen sulphide	✓	✓			✓			✓		✓	✓			✓
toxicity - algal/disease		✓			✓					✓	✓	✓	✓	✓
toxicity - oils		✓			✓					✓				
toxicity - chemical			✓											
toxicity - heavy metals	✓	✓			✓		✓			✓	✓			✓
decreased dissolved oxygen				✓				✓						
increased nutrients	✓	✓			✓		✓	✓		✓	✓			✓
changes to water pH		✓			✓		✓	✓					✓	✓
changes to soil pH		✓					✓	✓					✓	✓
increased wave action											✓	✓		
changes to wave climate							✓	✓					✓	✓
changes to tidal regime		✓			✓		✓	✓						✓
decreased invertebr. diversity		✓			✓		✓	✓		✓				✓
changes to invertebr. species		✓		✓	✓		✓	✓		✓				✓
decreased invertebrates				✓				✓		✓				✓
decreased salinity		✓			✓		✓	✓		✓				
increased salinity							✓							
disturbance by sight			✓			✓			✓		✓	✓	✓	✓
disturbance by noise			✓			✓			✓		✓	✓		✓
disturbance by waves											✓	✓		
disturbance by dogs			✓			✓			✓		✓			✓
disturbance by humans			✓			✓			✓		✓	✓	✓	✓
decreased roughness		✓					✓	✓						✓
increased roughness				✓		✓			✓		✓			✓
increased area		✓												
reduced shoreline length				✓			✓						✓	✓
changed shape or position		✓		✓	✓				✓	✓		✓	✓	✓
changed profile		✓		✓	✓		✓	✓	✓	✓		✓	✓	✓
decreased elevation				✓	✓				✓			✓	✓	✓
increased elevation		✓		✓	✓		✓	✓	✓	✓		✓	✓	✓
changes to soil texture		✓		✓	✓		✓	✓		✓			✓	✓
increased soil texture (sand)				✓										
decreased soil texture (mud)		✓					✓	✓						
deposition		✓		✓	✓		✓		✓	✓		✓	✓	✓
erosion					✓				✓			✓		✓
loss of fringing veg.				✓					✓		✓		✓	✓
seagrass loss				✓			✓	✓	✓				✓	✓
mangrove loss				✓			✓	✓					✓	✓
habitat fragmentation				✓									✓	✓
direct intertidal flat loss				✓									✓	✓

Section 2: Impacts

The impacts listed in Section 1 (Table III.1) are briefly described here, along with their relevance to the important habitat attributes of the six common migratory shorebird species modelled in the research (Chapter1). Each impact is numbered for cross-reference with Table III.1.

The information is drawn mainly from the research, but also from published information, personal observation and conversations with estuary resource managers.

A further reading list is provided because complex issues are dealt with briefly. The books and journals listed are available in government or university libraries, or by inter-library loan. Further references contained in the books and papers access a wide range of information. Strategies for managing these impacts are in Section 3, as are further references dealing with their management.

1) Direct intertidal flat loss

Intertidal flats are here defined as the areas between the mean high tide shoreline and 150mm deep at spring low tide, with less than 100% mangrove foliage projection cover. That is, the mudflats and sandflats in our estuaries.

Direct loss of these by filling, dredging, erosion, deposition and construction decreases shorebird feeding habitat.

Bar-tailed Godwit, Eastern Curlew and Pacific Golden Plover numbers and density (numbers per unit area) increase with area of the intertidal flat on which they feed. Also, these species and Whimbrel are more numerous on flats which are part of large assemblages of intertidal flat. Bigger areas and assemblages of intertidal flat also support more species together, including the less common species.

Reducing the area of intertidal flat may reduce its value to shorebirds out of proportion to the reduction in area, because it becomes less viable as a feeding area.

Relevant habitat attributes (used in the research): area of flat; area of surrounding flats within 1km; total intertidal area within 1km; perimeter length.

2) Habitat Fragmentation

This means the splitting up of continuous areas of intertidal flat into separate areas by intervening development.

Because more shorebirds and more species are found on flats which are part of large assemblages of flats, it follows that creating smaller isolated flats may reduce their value per unit area to feeding shorebirds. The birds' feeding efficiency may be maximised by using an area which can be ranged over while foraging, without flying.

Relevant habitat attributes: area of flat; area of surrounding flats within 1km; total intertidal area within 1km.

3) Mangrove Loss

Mangroves provide organic matter, the food of invertebrates. Mangroves reduce current velocity and wave action and trap and stabilise sediments. They provide cover for some shorebird species (and roosts). Mangroves may also be good indicators of biologically rich intertidal areas.

There are very strong links between the amount of fringing mangroves on intertidal areas and the numbers of some shorebird species, and total number of shorebird species, using them. Whimbrel and Greenshank numbers are strongly associated with the amount of mangroves growing on all surrounding shores. Tattler numbers are associated with the amount of mangroves abutting the intertidal flat.

In coastal lagoons, lower salinity regimes cause Swamp She-oaks (*Casaurina glauca*) to grow in the fringing zone rather than mangroves. The relationship remains if these fringing trees are included and the habitat attribute is considered as 'surrounding littoral trees'.

Loss of mangroves and other littoral trees from estuary shores may directly and indirectly impact shorebird feeding areas.

Mangrove cover on the intertidal flats (as distinct from fringing mangroves) was related positively in the study to numbers of Tattler, but was not related either positively or negatively to other shorebird species. However, measured cover only ranged to half of the flat vegetated at 40% foliage projection cover (creating 20% "mangrove cover" - see Appendix II) and most study flats had less than one tenth vegetated, and at only 5% density of foliage. High proportions vegetated (over 50%) and densities (over about 40%) of mangroves on intertidal flats may exclude feeding shorebirds.

The definition of the study flats excluded mangrove forest with 100% canopy cover. General observation indicated Whimbrel feed in mangrove forest, as do Eastern Curlew in low numbers (although not in dense *Rhizophora*, which has tangled roots). Tattler and Common Sandpiper remain close to the forest edge. Bar-tailed and Black-tailed Godwit, Golden Plover, Mongolian Plover, Stint, Knot, Marsh, Terek and Sharp-tailed Sandpiper and Curlew Sandpiper avoid 100% canopy cover.

The impact of mangrove loss from intertidal flats will differ with shorebird species and the proportions of mangrove cover. A balance needs to be maintained in shorebird feeding habitat conservation between the important inputs from mangroves and availability of open feeding areas.

Relevant habitat attributes: % surrounding mangrove; % mangrove cover; % adjoining mangrove (Tattler); % total ground cover (Tattler).

4) Seagrass Loss

Seagrass provides organic matter and habitat for invertebrates and fish. It grows on intertidal flats and on estuary floors, so provides both direct and indirect input into intertidal food webs. Seagrass also stabilises intertidal areas.

There was no direct link between seagrass density and numbers of feeding shorebirds on the study flats, except Tattler. Shorebirds fed on both exposed seagrass beds and bare flats. Seagrass cover related to Tattler numbers as a vegetation type and also as a component of total vegetation cover.

The impact of seagrass loss to most shorebirds could be considered indirect. Decreased seagrass removes a source of food and habitat for shorebird prey, and may destabilise intertidal areas.

Relevant habitat attributes: % seagrass cover; % total ground cover (Tattler). Only guidelines for % ground cover can be given.

5) Loss of Fringing Vegetation

This includes vegetation above the normal tide range (supralittoral, including saltmarsh) and terrestrial vegetation above the shoreline. Fringing vegetation shelters and stabilises shorelines, filters and absorbs runoff, and provides organic matter to adjacent estuarine systems.

Loss of fringing vegetation can impact feeding shorebirds directly by loss of buffers from disturbance. It can increase nutrient runoff from disturbed soils, increase erosion and consequent deposition of invertebrate-poor sediment on feeding areas (see next heading), or may have longer term impacts by reducing organic matter input into estuaries.

Relevant habitat attributes: % surrounding mangrove; % adjoining mangrove; % dry, % wet, % shallow ground at low tide; Secchi transparency; see also Disturbance Buffer Distances.

6) Erosion and Deposition

Different places in estuaries are linked in complex ways by currents, caused by catchment flows, tides and wave energy. Erosion in one place means deposition in another.

Erosion and deposition can be caused by changes to currents, runoff (volume, velocity and sediment load) and wave action, wind and physical action (eg. trampling, excavation). The erosion or deposition can affect the edges and surfaces of intertidal flats. The surfaces of intertidal flats are affected by currents and wave action on the upper portion of the tide, and by wind and direct runoff on the bottom of the tide. Both erosion and deposition can result in direct habitat loss to shorebirds.

Deposition is the more common direct impact on intertidal flats, but both impact shorebird feeding areas by:

(I) changing substrate texture, composition and surface relief. Erosion of overlying material (for example wind erosion of dry sand at low tide) can expose different underlying substrates. Deposition of new sediments can change the nature of flat surfaces. (See soil texture (7), roughness (11), below). Surface characteristics may impact feeding shorebirds.

(II) changing the elevation profile of flats in relation to water levels. Deposition may increase elevation so more of a flat dries or it drains earlier or more thoroughly on the outgoing tide. High areas are used less by most shorebird species. Erosion may reduce elevation beyond the depth useable by shorebirds (see elevation profile (8), below).

(III) changing the shape of intertidal areas. Perimeter (shoreline) length may change as flats become more or less convoluted in shape. Areas may become fragmented (see Habitat Fragmentation(2), above). Shorebird species number, and Eastern Curlew numbers, may be related to shoreline length (see shape and shoreline length (9), below).

(IV) changing the vegetation. Erosion may remove vegetation such as mangrove and seagrass, deposition may bury vegetation (short term) and may change elevation and therefore suitability for vegetation (long term). Instability itself can stop colonisation by vegetation. (See mangrove loss (3), seagrass loss (4), above.)

(V) changing benthic invertebrate populations. Changes to substrate qualities, or unstable substrates, may either reduce overall invertebrate populations, change species compositions which may remove an important prey species for shorebirds, or decrease the number of species, having the same effect.(See invertebrates (14), below.)

(VI) changing the area of intertidal flat. Areas can decrease by erosion, or by deposition (wind and wave action) building up material beyond normal high tide level. Areas can increase by removal of high material, or by deposition. If stabilised, this can lead to increased shorebird feeding habitat. (See direct habitat loss (1), fragmentation (2), above, and increased area (10), below.)

Because erosion and deposition are generalisations, these impacts are detailed further under their specific headings.

Relevant habitat attributes: all habitat attributes are potentially affected by erosion and deposition.

7) Changes to Soil Texture

Soil texture (sand, silt, clay and combinations of these - see Appendix II) and surface hardness are loosely related (sandy soils tend to be firmer on intertidal flats). There were no strong relationships between either substrate attribute and 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 to shorebirds. 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.

Relevant habitat attributes: Northcote texture class; mean surface hardness.

8) Changes to Elevation Profile

This means the height of the intertidal flat in relation to water level. Flats are not really flat - different areas of a flat have different heights, which are exposed for different durations in the tide cycle, and are either dry, soggy or shallowly covered at low tide.

The proportions of these different heights can be estimated to provide a rough measure of 'elevation'. A more precise measure (though not necessarily more accurate) can be made by surveyor's level, from a datum based on the mean high tide mark and indicated by vegetation (see Chapter 2: *Results: Elevation Profile Levels*). Though water levels change with the level of the low tides (0.0 to 0.8m at Middle Head) an estimate around mean low tide (0.3 to 0.6m) approximates normal availability of the different elevations to shorebirds (see Appendix II).

One or more of the complementary measures of elevation used in the study (% dry ground, % wet (soggy) ground, % shallowly covered ground and % 50-150mm deep at low tide) were very strongly related to numbers of three species of feeding shorebird. Bar-tailed Godwit, Whimbrel and Greenshank favoured areas with low or shallowly covered ground. Species number, including less common species, tended to increase with the proportion shallowly covered areas.

Dry ground at low tide is less useful to feeding shorebirds than soggy or shallowly covered ground. This relates to prey abundance and/or availability to the birds.

Impacts on elevation profile which increase the area of high and dry ground at low tide 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.

Changes within the range of levels including wet (soggy) and shallowly covered (<50mm deep) ground at low tide are less critical, given the variation in low tide heights over the tide cycle (but see other effects of erosion and depostion, above). On flats of high conservation value to shorebirds, elevation profile is a critical habitat attribute to protect.

Relevant habitat attributes: % dry ground at low tide; % wet (soggy) ground at low tide; % shallowly covered (<50mm deep) ground at low tide; % area 50-150mm deep at low tide.

9) Changes to Shape and Shoreline Length, or Position

Shape and area determine shoreline length. Flats with irregular shapes have greater shoreline lengths than flats of the same area with regular shapes.

Shape itself may affect shorebird disturbance levels if long narrow flats border sources of disturbance. Godwits, golden plover, smaller plover, stints, knots, Curlew Sandpiper and others avoid very narrow flats adjoining vegetation or shorelines.

Study flats with longer shoreline (perimeter) lengths were used by more shorebird species, but shoreline length was not separated from area. On otherwise high flats, the shoreline zone contains the wet and shallow elevations favoured by feeding shorebirds. Impacts which reduce shoreline length may reduce shorebird feeding habitat. Most impacts which affect shape and shoreline length will also affect area, elevation and other more critical habitat attributes.

Position relates to openness of the flat. Flats in the main channel have a high proportion of their perimeter bordered by open water. Flats in bays, coves and inlets are bounded by more land or mangroves. Proportion of open water surrounding the flat was the measure used in the study.

Proportion of open water related to numbers of 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 habitat attributes (see Chapter 1 - *The Estuarine Environment*). Excavations and constructions which alter the proportions of water and land around flats may directly or indirectly impact shorebirds.

Relevant habitat attributes: area of flat; perimeter length; % open water surrounding flat; all habitat attributes indirectly.

10) Increased Area

This can occur mainly through accretion or construction, and is opposite to 'direct habitat loss', above. Increased intertidal area is not an increase in shorebird feeding habitat unless it provides effective foraging. Accreting areas may be too unstable or poor in organic matter to be colonised by invertebrate prey. Adverse side affects of sedimentation (see below) on existing feeding areas may negate gains.

Constructed feeding areas need to provide the important habitat attributes quantified in Chapter 2 - sufficient area, fringing mangrove plantings, appropriate elevation and tidal regime, and with soil and water properties within the acceptable range (see Chapter 2, Table 2.19; also Section 3: *Size, Shape & Position*).

Relevant habitat attributes: all the important habitat attributes relate to provision of feeding habitat.

11) Changes to Roughness

Surface roughness (or smoothness) is referred to as microrelief and the unit of measure used was the variance of a series of measurements of surface depression depths (see Appendix II).

Although surfaces ranged from even to having depressions 0.3m deep, no direct relationships were found with feeding shorebirds. Microrelief did affect elevation (bumpy sites had more dry ground) so extreme humping may reduce shorebird feeding habitat. It may also affect security by limiting visibility for feeding shorebirds.

Microrelief values measured were of natural occurrence. Impacts which affect surface evenness, such as pugging, may affect invertebrate abundance and vegetation cover rather than the direct facilitation of shorebird feeding.

Relevant habitat attributes: microrelief variance.

12) Disturbance

Disturbance can be direct or ambient. Common sources of direct disturbance on estuarine feeding areas are people, dogs, wash from boats, noise from engines, and visual disturbance from people, boats, vehicles, aircraft etc which are not actually encroaching on shorebird feeding areas (see also ambient disturbance). Natural disturbance is also common, mainly from birds of prey and intraspecific aggression, but these are beyond management aims.

Shorebird reaction to direct disturbance can be either flight, leaving the feeding site; flight, but relanding either beyond the disturbance in distance, or after the disturbance in time; and running or vigilence but remaining on the ground - that is, being interrupted from feeding or forced to leave preferred feeding site.

The distance to disturbance (buffer) should be increased until reaction 4 is obtained. Using shorebird feeding habitat of high conservation value as buffers should be avoided. Another effect, exclusion of shorebirds from their full foraging range, is discussed under ambient disturbance below.

All shorebird species are affected by disturbance but larger species with longer flight or 'critical' distances or flocking species which need room for individuals to feed but react as a unit are more affected. Physical attributes of feeding areas - size, accessibility to people (by land or water) and surface hardness (soft surfaces discourage people and dogs) - also affect levels of disturbance.

Ambient or potential disturbance impacts feeding shorebirds by aliening feeding habitat. Alienation can be caused by direct sources mentioned above, or by terrestrial development or activity too close to feeding areas (insufficient buffer). This occurs by limiting shorebird movement onto (i) disturbed portions of foraging areas, or (ii) entire foraging areas, because the birds perceive an unacceptable level of potential disturbance or predation.

Relevant habitat attributes: area of flat; mean surface hardness; see also Disturbance Buffer Distances.

13) Salinity Changes

Estuary water salinity varies with distance to the mouth, stage of tide (daily) and rainfall and river flow (variable). Consequently the salinity of waters flowing over any one intertidal area may naturally range from fresh to seawater. The water salinity regime is a better gauge of salinity levels, roughly summarised in this study by the mean salinity (electrical conductivity) over the full tide cycle.

Water salinity affects soil salinity, vegetation and invertebrate populations. Brief departures from the normal regime are generally tolerated; changes to salinity regimes have major impacts. Salinity regimes can change permanently by structures or depositions restricting tidal flow, and by outfalls and other sources of inflow.

Tidal restrictions cause salinity regimes to become less saline upstream of the restriction if there is freshwater inflow. Salinity increases from evaporation if there is no freshwater inflow. These changes are accompanied by changes to flooding regimes, currents and wave patterns, and turbidity levels (saline water carries less sediment).

Many shorebird species feed in freshwater wetlands as well as estuaries, such as Sharp-tailed Sandpiper, Greenshank and Marsh Sandpiper. Salinity regime changes will impact shorebirds indirectly rather than directly, mainly by changes to invertebrate abundance or species composition.

Where tidal restrictions cause increased salinity beyond seawater (and decreased tidal flooding) invertebrate populations can decrease. Where salinity is reduced by freshwater inflow, species composition can change and the number of species can be reduced. Prey species important to some shorebird species may be lost.

Eastern Curlew numbers were higher on more saline intertidal flats than flats with brackish regimes. Eastern Curlew prey - ghost shrimps (yabbies) and small crabs - may be more abundant in more saline regimes. Numbers of the other common species did not relate strongly or at all to the range of salinities measured in the study.

For a discussion of vegetation changes with salinity changes, see Section 3, B5: *Salinity Changes*.

Relevant habitat attributes: Mean salinity (conductivity); elevation profile measures; Secchi transparency.

14) Changes to Invertebrates

Invertebrate animals living in the soil or on the surface of intertidal flats are the food of migratory shorebirds in estuaries. Management of invertebrate populations is difficult with the current level of knowledge of (a) invertebrate ecology, and (b) preferred shorebird prey species.

This research uses shorebirds as indicators of good and bad shorebird habitat, but the invertebrate populations are in most cases the link. Therefore habitat attributes identified as important to shorebirds are probably important to invertebrates.

Invertebrate populations can be impacted by habitat change, pollution and harvesting. The effects of these can be decreased invertebrates, changes to invertebrate species but no overall change to abundance or number of species, and reduced species number where one or a small number of species dominate in the altered conditions.

All of these changes to invertebrate fauna can adversely affect shorebirds, but prediction of the impacts on shorebirds is difficult, and will differ with species. Management at this stage constitutes minimising change to invertebrate habitat, and controlling pollution and harvesting.

Relevant habitat attributes: Invertebrates are not dealt with as habitat attributes in the modelling. All habitat attributes important for shorebirds have the potential to be important for invertebrates (see Chapter 5).

15) Changes to Tidal Regime

Tide ebb and flow affects (a) flooding regime (water level), (b) water exchange and estuary circulation, and (c) currents and wave action. Any interference in the natural tidal flow (tidal regime) by deposition or construction which restricts tidal flow, could effect these three aspects of water movement and impact shorebird habitat.

(a) Flooding regime. Water levels change naturally on intertidal flats over daily, monthly and yearly cycles. Tidal restrictions cause water to be either held at higher levels for longer or remain at low levels, depending on degree and level of restriction.

For example, walls which are overtopped at high tide levels maintain high water levels behind them on low tide. High walls with seepage or inadequate pipes keep levels behind low because there is insufficient time in the tide cycle for them to fill (see Section 3, A6: *Tidal Regime*, and cross-references therein). These changes may affect vegetation and invertebrate populations.

(b) Water exchange and circulation. Tidal restrictions limit water exchange with the estuary and the sea, and may inhibit circulation of fresh and saline water, causing changes to salinity, turbidity and dissolved oxygen, and allowing nutrients and pollutants to accumulate. Impacts of these on shorebirds are discussed under their specific headings.

(c) Currents and wave action. Restrictions slow currents and break wave action. In the still water sediments tend to accumulate, changing elevation profile and substrates, affecting vegetation and invertebrates (see erosion and deposition (6), above.)

Relevant habitat attributes: all habitat attributes are potentially affected by changes to tidal regimes. These changes are dealt with in greater detail in Section 3.

16) Changes to Wave Climate and Wave Action

Wave climate is the regime of wave action a site receives from the range of weather patterns and tides experienced there. Wave action is the physical effect of waves breaking on or flowing over an intertidal area.

Changes to wave climate can be caused by changed estuary shoreline shape and bottom shape, or deposition and erosion (particularly at the mouth). Wave action can increase (or decrease) due to these or increase from boat wash.

Increases in wave action increase erosion and deposition (see erosion and deposition (6), above) or directly affect vegetation and invertebrates. Wave action can also directly affect feeding shorebirds by making conditions unsuitable for shoreline foraging.

Relevant habitat attributes: all habitat attributes are potentially affected by changed wave climate and wave action. See also Table 2.19 - wave heights.

17) Changes to Soil and Water pH

Although surface pH levels of intertidal flats are relatively neutral, low estuarine land (above or below high tide level) can have very acid soils and subsoils. Very acidic runoff onto intertidal areas has occurred following excavation of acid coastal soils. Acidic runoff forms toxic compounds which may affect invertebrate abundance (and fish), thereby impacting shorebirds (see toxicity (20), below).

Pollution can cause excessively alkaline conditions which may also affect invertebrates.

18) Nutrient Changes

Available nutrients, necessary for plant and animal growth, come to intertidal flats from sediments and organic matter transported from the catchment, and the breakdown of organic matter *in situ*. Marine sediments from the estuary mouth are generally nutrient poor.

Limiting nutrients are normally nitrogen or phosphorus. Phosphorus (in available orthophosphate form) was measured as a crude index of available nutrient levels on the study flats. Those flats with soft sediments and turbid waters fringed by mangrove and enclosed in bays or inlets had higher phosphate levels. Nutrient levels also related to estuary size and amount of high-fertility geology in the catchment. Smaller estuaries which had low or high but infertile catchments were not as naturally nutrient rich (see Chapter 1: *The Estuarine Environment*).

Greenshank and Pacific Golden Plover numbers were positively related to nutrient levels (bird number and nutrient level increased together), as was shorebird species number. Whimbrel and Tattler numbers were related to amount of mangrove, though not with measured nutrient level directly.

Within the natural range measured, more nutrients supported more shorebirds and shorebird species, with the link presumably invertebrates. Decreases in available nutrients can occur when deposition of marine sands (or nutrient-poor sands from the catchment) occurs over a flat (see erosion and deposition (6), above). Removal of wetland vegetation may result in long term loss of a nutrient source (though nutrients may increase from disturbed soils) (see mangrove loss (3), loss of fringing vegetation (5), above, organic matter (22), below). Nutrient increase is a more common problem from catchment disturbance or land use, including urbanisation. Reduction in sediment load regime (turbidity) may reduce a flat's nutrient regime.

Excessive increases in nutrients caused by unnatural inflows of nutrient-rich run-off or effluent, can overload wetland systems causing changes to invertebrate abundance, blooms of toxic algae, anaerobic waters, vegetation die-off and in extreme cases avian desease.

Shorebirds may be less sensitive to excess nutrients than other estuarine organisms, for example seagrass, fish or oysters (or people eg. swimmers). Shorebirds attracted to vegetation cover (Tattler) may be affected by seagrass dieback if seagrass constitutes the vegetation cover. Effects will change from place to place depending on cover composition. In Moreton Bay sewage effluent-affected flats had less seagrass and Tattler than unaffected flats but more small worms, Curlew Sandpiper and Knots (see Thompson (1993) in *Further Reading: Nutrients, Pollution and Algae*). Management action to control a nutrient inflow to estuarine waters may first be motivated by other considerations, but affects on shorebirds, via invertebrates or vegetation cover, need to be considered.

More subtle nutrient increases, particularly accompanying sedimentation, may encourage colonisation of open flats by mangrove, which in extreme cases may exclude feeding shorebirds.

Nutrient levels in estuaries affect and interact with water and soil chemistry, vegetation and fauna in complex ways beyond the scope of this manual. Some management issues will need more detailed investigation of certain biochemical interactions. See the Further Reading list below for a lead in to detailed information on nutrient cycles in estuaries, and Further Reading in Section 3 for their management.

Relevant habitat attributes: orthophosphate, Secchi transparency, % surrounding mangrove; % mangrove cover.

19) Decreased Dissolved Oxygen

Dissolved oxygen in estuarine waters affects chemical processes, surface soils and estuarine life. Wave and tide action, and circulation due to salinity, keeps dissolved oxygen levels high.

But in intertidal areas restricted from adequate water movement, water can stagnate. Decreased oxygen levels can increase nutrient availability and therefore plant growth, the breakdown of which consumes more oxygen. The anaerobic conditions can reduce invertebrate numbers or species number, and produce obnoxious odours.

Organic pollutants may produce the same effect at outfalls. Dissolved oxygen levels thus reflect the health of intertidal areas and are used in monitoring water quality. (See also tidal regime (15), hydrogen sulphide (21), nutrients (18)).

20) Toxicity

Estuaries are ports and population centres. Toxic materials can enter estuaries by effluent outfalls, accidental release or gradual accumulation from runoff and leaching or waterborne activities. Shorebirds can be affected directly by ingesting toxic substances or contaminated prey and having plumage fouled. Effects can be poisoning, increased susceptibility to disease, fatigue or predation, or decreased reproductive success. Indirect effects can be changes to habitat (eg.vegetation) and food availability (invertebrates).

Shorebirds are near the top of the food pyramid in estuarine intertidal flats - a depositional environment subject to accumulations of substances. This and the cumulative (biomagnification) effect of some toxins makes shorebirds susceptible.

Examples of toxins are:

- heavy metals from mine runoff, industrial effluent or leaching;
- organochlorins and chemical compounds from agricultural or urban runoff, industrial and municipal effluent;
- petroleum hydrocarbons from boats, shipping, runoff or effluent;
- toxins from toxic algae or disease from bacterial/viral infection

Present knowledge doesn't allow specific pollution guidelines for shorebirds, but some precautions are recommended in Section 3. Also see references on pollutants and ecotoxicology in *Further Reading*.

21) Hydrogen Sulphide

Like dissolved oxygen, presence of hydrogen sulphide is an indicator of anaerobic conditions and possibly a degraded environment. Mangrove soils, being saturated, become oxygen depleted and have natural quantities of hydrogen sulphide (the odour of mangrove mud) but excessive amounts on the undisturbed surface of intertidal flats (resulting in a stink) will indicate pollution.

This may be more offensive to people than shorebirds but more direct effects of organic pollution will adversely impact shorebirds (see nutrients (18), toxicity (20), above).

22) Changes to Organic Matter

Organic matter enters intertidal flats from the catchment (or beach washed) and local plant and animal breakdown. It is a source of nutrients, and particulate organic matter (detritus) is the food of many invertebrates on intertidal flats. The amount of organic matter in intertidal flat soils can be roughly gauged from the colour and texture - light sands are low in organic matter, dark mangrove mud is high in organic matter.

The relationship between both shorebird numbers and species number, and either nutrient levels, amount of surrounding mangrove or both (see nutrients (18), mangrove loss (3), above), indicates that organic matter plays an important role in shorebird feeding habitat suitability.

Reductions in organic matter can be caused directly by deposition of organically poor sediments over flats, and indirectly by reduced sources of organic matter locally or in the catchment, and the causes of deposition (see erosion and deposition (6), above).

Increases in organic matter can be caused by nutrient- or organic matter-rich runoff and effluent. Excessive amounts of organic matter can overload estuarine ecosystems. Where nutrient levels are high breakdown of organic matter can cause excessive phytoplankton and other plant (especially algal) growth, de-oxygenation and resulting degradation as described for nutrient levels (see nutrients (18), algae (24)).

Organic pollution can reduce species number of invertebrates (not necessarily overall abundance), which can remove important shorebird prey species.

Relevant habitat attributes: % surrounding mangrove; % adjoining mangrove; % mangrove cover; % seagrass cover; % total ground cover; orthophospate.

23) Turbidity Changes

Intertidal areas are mostly deposited by water. Typically river and creek flows carry sediment from the catchment on currents which slow and increase in salinity when they meet incoming tidal currents, causing the sediment load to settle out. Turbidity is a measure of the sediment load, and the main measure of turbidity used in the study was water (Secchi) transparency (see Appendix II).

Whimbrel and Greenshank used flats where there was high sediment loads rather than flats with clear water. Shorebird species number on the flat also related to amount of water sediment. Natural sediments 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 (see Chapter 1 - *The Estuarine Environment*), both important attributes of shorebird feeding habitat. Natural fine-sediment regimes are integral to the creation of good feeding habitat for many shorebirds.

Reductions in natural turbidity - that is sediments with appropriate levels of nutrients and organic matter - may be caused by increased seawater inflow or increased nutrient-poor and organic matter-poor sediments.

All turbidity is not good, and the guidelines in Chapter 2 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 or degrade the intertidal environment in other ways (see relevant headings).

Changes in turbidity within the guidelines for shorebird habitat conservation may degrade other natural values in an estuary. Seagrass beds grow in clear waters in which light can penetrate and are affected by high levels of turbidity. Estuarine management needs to protect all conservation values in an estuary. Actions based on conserving one aspect at the expense of another need careful consideration of ecological impacts and conservation priorities.

Relevant habitat attributes: Secchi transparency; suspended solids; orthophospate and all other habitat attributes indirectly.

24) Algae

Three broad types of algae can affect shorebird feeding areas directly:

- algae (Dinoflagellates, Diatoms) mutiply in brackish, oxygen-depleted, nutrient overloaded water and some species produce toxins;
- filamentous algae grow on some intertidal lat surfaces. Excessive amounts may inhibit foraging by shorebird species which probe in the substrate; and
- seaweeds (macroalgae) such as Neptune's Necklace (*Hormosira banksii*) which grows on some flats, or Kelp (*Ecklonia radiata*) washed ashore, can contribute to vegetation or ground cover on flats (see mangrove loss (3), vegetation cover (25)).

Algae is a natural part of estuarine intertidal areas, providing food and habitat for zooplankton and larger invertebrates, fixing nitrogen and producing oxygen. Imbalances caused by excessive nutrients and or restrictions on water flow can create excessive algal blooms. These can indicate serious ecological problems or may impact shorebirds, public amenity or other estuarine values.

The effect of dense algal growth can damage estuarine wetlands (eg. blocking light to bottom plants) or their die-off and decay can cause oxygen depletion and fish and invertebrate deaths.

Relevant habitat attributes: % total ground cover. See *Further Reading: Nutrients, Pollution and Algae.*

25) Changes to Vegetation Cover

Vegetation on intertidal flats (distinct from fringing vegetation) may be:

- mangrove trees, bushes and seedlings. Grey Mangrove *Avicennia marina* with vertical aerial roots is the dominant species. Northern estuaries may have *Rhizophora sp.*, which has tangled roots and occupies more ground area per plant;
- seagrass, mainly Eelgrass *Zostera capricorni* in variable density to 100% ground cover when exposed and prostrate. Unstable sediment can be colonised by low, broadleafed *Halophila ovalis*, and more brackish shallows may have *Ruppia* species. Low spring tides may expose Strapweed *Posidonia australis* ;
- occasionally seaweed (see Algae (24), above);
- filamentous algae, either as a thin film, or in brackish coastal lagoons algal mats may develop;
- brackish areas may also have Common Reed (*Phragmites australis*) or rushes (eg. *Juncus* sp.) .

Tattler numbers were greater on study flats with vegetation or oyster cover (total ground cover). Excessive vegetation can affect availability of shorebird feeding space; surface foraging conditions and therefore invertebrate prey availability; and predator visibility for feeding shorebirds. See mangrove loss (3), seagrass loss (4) and algae (24), above.

It also affects erosion and deposition by stabilising sediments and slowing currents and wave action. See erosion and deposition (6), wave climate and wave action (16), above.

Vegetation on flats contributes organic matter to invertebrate food sources, affecting shorebird prey abundance. See organic matter (22), nutrients (18) and invertebrates (14), above.

Relevant habitat attributes: % mangrove cover; % seagrass cover; % total ground cover (Tattler). Vegetation cover can affect elevation profile (% dry, % wet etc).

26) Cover by Structures

Wharves, groynes and oysterfarming racks all displace shorebird feeding habitat. Wharves and jetties alienate the ground under them, and also either side to the respective disturbance distance of each species that is kept away by disturbance or perceived potential predation (see disturbance (12), above).

Rocks from groynes and breakwaters litter areas adjacent to the walls, changing the feeding environment. Habitat may be alienated by disturbance as with wharves, and by blocking visibility and fragmenting continuous areas.

Oysterfarming structures are by far the most extensive structures on intertidal flats and add greatly to ground cover on some flats. General observation indicated that Tattler readily feed under oyster racks which do not have solid covers. Whimbrel and Eastern Curlew feed close to racks but rarely underneath (and racks are often too low). Godwit, though abundant, were infrequently seen near racks.

Disturbance from oysterfarming work can limit shorebird feeding areas but generally this affect is temporary and of low impact because workers stay in one place for long periods.

Because habitat area and continuity are important habitat attributes (see direct habitat loss (1), habitat fragmentation (2), above) an accurate way of gauging habitat loss from structures is proposed in Section 3 (A9: *Cover by Structures* for oysterfarming racks, A5: *Disturbance* for others).

All structures on intertidal flats may affect deposition, changing the elevation profile (see elevation profile (8), erosion and deposition (6), above).

Relevant habitat attributes: area of flat; area of surrounding flats within 1km; total intertidal area within 1km; perimeter length.

27) Changes to Water Level

Water levels fluctuate over a long term constant range in tidal wetlands and organisms are adapted to this. Reduction or increase in overall water level can be caused by tide restrictions, inflows, and floods and low catchment flows.

Effects of tidal restrictions on feeding shorebirds are discussed under Tidal Regime. Inflows (eg. outfalls) can cause erosion and deposition, changed salinity and pollution depending on content, as discussed under the relevant headings. The increase in water level itself can reduce feeding area and change invertebrate abundance or species (see elevation profile (8), above).

Generally, increased water level which permanently floods intertidal areas reduces shorebird feeding habitat and may change invertebrate species; permanently decreased water level which dries intertidal areas for long periods will reduce shorebird feeding areas and invertebrate abundance. Beyond these extremes generalisations can't describe all changed flooding regimes or their effect on shorebirds (see tidal regimes (15), elevation profiles (8), salinity (13), vegetation cover (25); also Section 3, A6: *Tidal Regime*).

Flood and drought are not manageable but affect management decisions. Flood mitigation programmes have constructed floodgates, drains, levees and training walls which change tide regimes and water levels behind, and may increase flood height or velocity in the estuary. Periods of low flows in rivers and coastal lagoons result in deposition at the mouths restricting tidal flow and reducing water levels. These change the relative importance of different areas and estuaries to shorebirds over time.

Conservation value assessment needs to take these changes into account. For example, flats in coastal lagoons which are subtidal in high rainfall periods may become important shorebird habitat in droughts when other wetlands dry. See Section 3, A10,B15: *Changes to Water Level.*

Relevant habitat attributes: water level potentially affects all habitat attributes.

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See also Section 3: *Further Reading.*

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Section 3: Management Strategies

Impacts on shorebird feeding habitat were identified in Section 1 and described in Section 2. Important attributes of shorebird feeding habitat were identified in Chapter 1. This section suggests some strategies by which the impacts on the important habitat attributes might be managed.

The strategies have been drawn from the research results, published information and discussions with estuary natural resource managers. The habitat attributes identified in the research are combined into four sections:
(A) Size, Shape and Position;
(B) Vegetation;
(C) Substrate Type & Elevation Profile; and
(D) Water Properties.

Within each section strategies for the relevant impacts from Section 2 are listed. This structure brings together all management strategies for a habitat attribute group. Cross referencing links impacts within the section and numbering in brackets corresponds to impact numbers in Sections 1 & 2.

Further Reading lists publications concerning management of the impacts and attributes, because each strategy is only briefly summarised. These publications, or further references contained in them, serve as a source of detailed information to develop management strategies.

These management strategies are only for one aspect of estuarine conservation, for use in conjunction with conservation priority decisions and the management requirements of other estuarine values.

(A) Size, Shape and Position

Habitat attributes (identified by the research): Area of flat; Area of Surrounding Flats (within 1km); Total Area of Intertidal Flat (within 1km); Perimeter Length; % Open Water Surrounding Flat; % Total Ground Cover.

Impacts to Manage (from Section 1):

A1: Direct Intertidal Flat Loss (1), Habitat Fragmentation (2):

- Avoid development which encroaches on intertidal areas (either from landward eg. landfill, or seaward eg. dredging). Use the guidelines for acceptable habitat area (Chapter 2) and existing local or state protection (eg. local authority planning strategies can give nominal protection to intertidal areas) and apply these to development proposals.

- Determine the area of adjacent intertidal flat which will be alienated by developments (see A5:Disturbance, A10: Cover by Structures, below) and include this in feeding habitat loss estimates.

(A) Size, Shape and Position (cont.)

- Avoid splitting continuous areas or causing a barrier to foraging shorebirds.

- If a choice must be made, give lower conservation priority to isolated intertidal areas than same sized areas contiguous with or near other intertidal habitat. This principle applies if the two areas are of similar conservation value in other respects eg. elevation. Some species (Greenshank, Tattler) were found on small and large areas.

- Ensure that any lost shorebird feeding areas are compensated for by construction or enhancement of alternative areas, and ensure these areas are of effective design. Considerations are: (I) the area to be converted to alternative habitat must be currently of low conservation value; (II) it must be able to support all shorebirds displaced by the habitat loss and provide appropriate habitat attributes (Chapter 2) and invertebrate populations; and (III) it should be established before the habitat loss. This requires the time needed for site selection, design and construction, and 2-3 years for stabilisation and invertebrate colonisation. See also A4:Increased Area, and A6: Tidal Regime,below.

- Construction of additional shorebird feeding habitat has been found overseas to increase shorebird use of nearby natural areas, possibly through increasing shorebird habitat availability in the area or estuary.

A2: Erosion and Deposition (6):

- Avoid changes to estuary shoreline, mouth or bottom shape which may change currents and wave patterns (see also A7: Wave Climate and Wave Action, below).

- Ensure hydrological surveys and modelling are done as part of the E.I.S. of any proposal affecting estuary shape.

- Ensure that counter measures of any changed currents or wave patterns, such as groynes, are included in the proposal's design and costing.

- Minimise erosion of intertidal feeding areas by stabilisation works or manipulation of eroding forces, complying with the above considerations.

- Promote or protect pioneering vegetation on erosion prone feeding areas, especially seagrass. Monitor pioneering mangrove density and control if shorebird feeding area is restricted by excessive growth (see A8: Vegetation Cover, below).

- Avoid sediment-rich runoff from point-sources which may smother or build up feeding areas. Apart from stopping the source, silt traps, tailings dams and artificial wetlands can stop sediment reaching the estuary. This includes short term sources such as building sites (see also A4: Increased Area, below).

- Avoid vegetation loss on foreshore areas and steep catchment slopes. Maintain a buffer of vegetation around estuary shores if possible (see B3: Loss of Fringing Vegetation, below).

- Monitor elevation profile of shorebird feeding areas prone to deposition to ensure areas remain at the best elevation in relation to low tide (see (C) Elevation Profile, below).

- Excavation can restore areas of former high conservation value to shorebirds which have built up excessively (see (C) Elevation Profile), but consider hydrology to ensure sustainability of landform, and side effects.

A3: Changes to Shape, Shoreline Length or Position (9):

- Avoid changing intertidal area shape to long thin shapes, bounded by land or vegetation and particularly adjacent to development and disturbance.

- Provide flats of such shape with adequate buffers landward (see A5: Disturbance, below).

- Avoid constructions which reduce shoreline length, even if area is unaffected (eg. a wall along one side of an intertidal area).

- Be aware that changes to the proportion of a flat bounded by open water may change its value to some shorebird species (and affect sediment regime, currents, wave climate, vegetation).

- Estuary-wide or regional conservation strategy should protect intertidal areas in inlets and bays as well as those with open aspect, because different species use each type of area.

A4: Increased Area (10):

- Be sceptical of the value of accreting intertidal area. It may indicate a process detrimental to shorebirds and other estuarine natural values. Unnatural rates of sedimentation should be controlled by strategies suggested in A2:Erosion and Deposition, above.

- Assess the sediment material for organic content. Marine sands and subsoil from the catchment are low in organic matter and are likely to be inferior for invertebrate colonisation to the substrate being covered. Tests should be made for toxicity and other harmful properties if these are suspected (see B10: Toxicity, below).

- Monitor the elevation profile (see (C) Elevation Profile, below), vegetation and invertebrate abundance and species (see C7: Invertebrates, below) of accreting areas to determine if shorebird feeding areas are being created or buried, and that vegetation and other estuarine values are not being degraded.

- Take action listed under A2:Erosion and Deposition, above, if estuarine values are being degraded by accreting intertidal areas.

- Stabilise moving intertidal areas by vegetation (seagrass, fringing mangrove) or works (eg. groynes) and protect pioneering vegetation in unstable areas. See B14:Vegetation Cover, below.

(A) Size, Shape and Position (cont.)

- Construct or enhance shorebird feeding areas (and roost sites) where appropriate (eg. to compensate for habitat loss and to enhance areas of low conservation value). See considerations under A1: Direct Intertidal Flat Loss, above. Use guide values in Chapter 2 to help in the design.

- If constructed habitat is more than about 2 km from existing feeding and roosting habitat, a roost area should be incorporated. Make this just above spring high tide level, with a gradual rise from mid-tide level, bare of vegetation or with sparse low vegetation only, with a 100m undeveloped buffer landward (the first 30m treeless), and incorporating a barrier to disturbance sources. It is much better if this can be an island (or multiple islands), or at least a point with restricted human access. Size depends on potential shorebird numbers, but no less than 30m across. See Chapter 6 and Appendix IV.

A5: Disturbance (12):

- Use Table 2.20 and accompanying text (Chapter 2) to identify disturbance levels and their required buffer distances.

- Calculate the likely area of alienated feeding habitat caused by foreshore development from the disturbance distances of the species involved at the likely level of disturbance, and the length of shoreline affected. Add this to any physical habitat loss when assessing impact. For public wharves, jetties etc subject to frequent disturbance, this area is the length plus disturbance distance (over intertidal areas), by the disturbance distance either side.

- Control disturbance by either providing buffers (areas of undisturbed land between the disturbance source and the feeding areas) or by controlling the disturbing activity. Some disturbance sources can be controlled, particularly illegal or obnoxious (to people) activities. Others need a buffer. Shorebird rights and human rights need to be balanced.

- Buffers are more effective if visual disturbance is reduced by screening vegetation (or fencing, mounding). Tall vegetation (>2m) should not be closer than 10m to shorebird feeding habitat.

- Disturbance sources observed during the study, and their level of disturbance are listed in Table III.2, along with some suggested control strategies.

- Liaison and education is an important part of people management, such as media releases in local newspapers and radio, brochures and information at government shopfronts and local retailers, interpretation activities such as seasonal ranger walks, presentations to and consultations with user groups such as fishing, sailing and pony clubs, liaison with professional groups and businesses, chambers of commerce and tourist boards.

Table III.2

Disturbances to feeding migratory shorebirds, and suggested control strategies.

SOURCE	EFFECT	STRATEGY
Boats: fast and close Jet Skis Aircraft: low Off-road vehicles	High Key: Tend to cause high degree of disturbance - causing flocks to leave feeding areas.	Boats: speed limits in co-operation with MSB. Jetskis: designated areas >200m from shorebird feeding habitat. Aircraft, low: restrictions on altitude (1 000 ft) in co-operat-ion with air traffic authorities. Off-road Vehicles: prohibition, sign posting, fines, blocking access.
Crabbing Boats landing Bait collecting Horseriding Kayak/surfski paddling/ windsurfing: close & landing Swimming, Running	High Key: Recreational activities tend to occur on firm sandy inter-tidal areas. Disturbances limit shorebird use of areas rather than flush them completely. Crabbing: boats (usually profess-ional) navigating in close to feed-ing (and roosting) areas repeated-ly can cause high levels of dist-urbance.	Balance required between shore-bird feeding and human recreat-ion. Signing and buffer zones in some areas suitable for segregat-ion into recreational areas and shorebird feeding areas. Areas of very high conservation priority for shorebirds may need to be signed and patrolled on weekends/public holidays during season. Backed up by media announcements, interpretation activities and contact with clubs/estuary user groups. Crabbing: Restrictions on use of key areas of very high conserv-ation value to shorebirds during season, in consultation with businesses, professional association and Fisheries.
Fishing Beachwalking Oysterfarming Boats: slow	Low Key: Tend to cause localised disturbance only - interrupting shorebird feeding, alienating parts of feeding (and roosting) areas, or forcing some birds to fly short distances.	Mostly compatible with shorebird feeding habitat conservation. Allowable at shorter buffer distances and inside buffer areas for high key disturbances. In high conservation value areas can be restricted to appropriate buffer distances by signing, patrolling and liaison with user groups.
Ambient: roads people	Low Key: Tend to alienate nearby shorebird feeding areas.	Buffer, screening vegetation, fencing or earth mound (or viewing hides) between visual disturbance and feeding area.
Dogs	Cause high disturbance levels when allowed to chase shorebirds. Dogs under control (on leash) are Low Key (see Beachwalking, above).	Restrictions in co-operation with local authority on affected areas. Signing, patrolling and prosecuting on sites of very high conservation priority.

(A) Size, Shape and Position (cont.)

- Co-operation will be needed between authorities if regulations are to be introduced and enforced, eg. Fisheries, MSB, aviation authorities, local government, Public Works, police, EPA, NPWS and Forestry.

A6: Changes to Tidal Regime (15):

- Generally, avoid changing the tidal regime from 100% natural tidal range. The effects of changing tidal regime are difficult to predict.

- Constructions (eg. walls and culverts under roads etc.) need to have pipes or gaps to provide tidal flow sufficient to allow full filling and emptying in the time available in the tide cycle. Even minor restrictions can slow filling and emtying flows, resulting in shorter durations of high and low tide.

- Pipes and gaps need to be at a low level to allow natural drainage on low tide, and need to be large enough to (1) carry sufficient volume of water, and (2) not concentrate the flow to the extent of causing erosion.

- Ensure a hydrological study is made as part of an E.I.S. and adequate engineering requirements are adopted in the design (and costing) to accommodate the full flow needed.

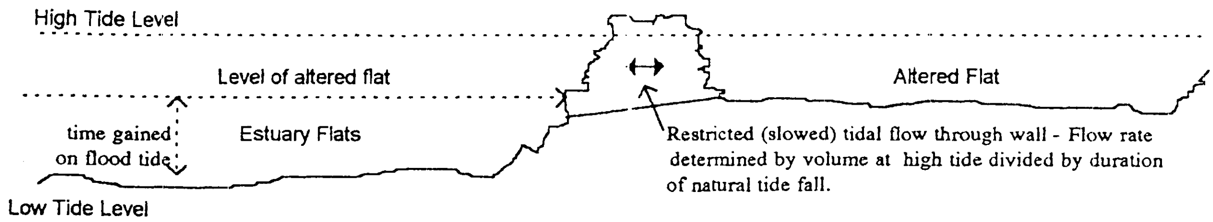
- Small restrictions at ground level, or seepage through rock walls, connecting the estuary to intertidal areas of higher elevation than the estuary flats can 'stagger' the tide (Fig. III.1). This has been suggested to benefit feeding shorebirds because the artificial low tide within occurs after natural areas have begun to flood on the incoming tide, providing extended feeding time on a flat which has flooded for the same duration on the high tide.

  However, the different tidal regime of such areas may produce directly, or indirectly through changed sediment, a depauperate invertebrate fauna either in abundance or species. This may be less valuable to some or all shorebird species than if its tidal regime was natural. Small shorebirds (eg. Sharp-tailed, Curlew Sandpipers and Stints) which benefit from continuous feeding, may be particularly helped, provided their prey is available.

This type of managed tidal regime can be useful in areas which (i) would not otherwise be available at all (artificial wetland), (ii) flooded too briefly on high tides (see (C) Elevation Profile, below), (iii) compensate for lost high tide feeding habitat (fresh or brackish wetland) formerly used by small shorebirds, and (iv) when associated with a roost or artificial roost where birds congregate at mid to high tide. Conversion of existing intertidal flat of high conservation value to shorebirds to this type of regime is of doubtful benefit. An alternative on high elevation sites is to reduce the level by excavation (see C3: Erosion and Deposition, below).

Figure III.1

A tidal restriction which slows the tidal flow to a high flat can give durations of flooding equal to low-level flats over a narrower tidal amplitude, and provide exposed intertidal areas for a time after natural areas have begun reflooding on the incoming tide.



Managing artificial estuarine wetlands and their waterlevels is complex and a new field of study in Australia. There are overseas studies (see *Further Reading*) but their local applicability is unknown. Artificial habitat is becoming an important shorebird conservation measure. See also A1: Direct Habitat Loss, Fragmentation, above, and A10: Changes to Water Level, below).

- A related topic, the flow of tidal water into fresh or brackish wetlands (such as may occur on spring tides or through works) is dealt with under B5: Salinity, below.

A7: Changes to Wave Climate and Wave Action (16):

- Ensure hydrological studies include modelling of wave climate and effects on erosion and deposition.
- Avoid changes to estuary shoreline and bottom shape, particularly changes to the mouth.
- Ensure measures for mitigating changes to wave climate, particularly the increase in wave action, are included in design and costing of proposals (breakwalls at the large scale, structures, vegetation on a smaller scale).
- Reduce boat wash in problem areas by restricting speed to 4 knots, and/or creating buffer zones. Smaller waterways can be limited to non-motorised boating (mainly canoes). Breakwaters or structures like those used by oysterfarmers can protect sensitive areas from unavoidable wash such as from an adjacent navigation channel.
- Use a maximum wave height at the shore of 60mm as an aim value, to maintain shoreline foraging ability by shorebirds.
- See also A2: Erosion and Deposition, above.

(A) Size, Shape and Position (cont.)

A8: Changes to Vegetation Cover (25):

- Increasing vegetation cover, beyond about 40% foliage projection cover, may displace shorebird feeding habitat, depending on area colonised. Examples are mangrove germination on accreting flats, mangrove colonisation of open saltmarsh (feeding and roosting habitat), sedge growth on building sandbars and reed colonisation of flats in coastal lagoons. Shorebird conservation needs to be balanced with other conservation priorities in these cases.

- Mangrove seedlings (single-stemmed upright plants to about 400mm) may be in long-term equilibrium and not a threat to feeding space if irregular floods or wave action stop them maturing. Where seedlings are maturing into larger bushes action may be needed to reduce density below 40% foliage projection cover if extensive areas are affected.

- Manual vegetation removal is preferable in acquatic environments. Mechanical methods need care to avoid damage and sedimentation. Herbicide use needs careful trials before widespread use, to avoid contamination to the environment, particularly non-target plants and invertebrates (see C7: Invertebrates). Dalapon (sodium dichloropropionate) has been used on *Spartina* in intertidal areas overseas without reduction in invertebrate or bird numbers, but side-effects, or applicability locally, are not known.

- Mangrove seedlings and aerial roots and seagrass contribute to Tattler habitat. See discussion of Tattler habitat conservation under A9: Cover by Structures, below.

A9: Cover by Structures (26):

- Consider wharves, jetties and other waterfront structures as displacing shorebird feeding habitat under them and either side to the disturbance distances of the relevant species (see A5: Disturbance, above), and apply strategies listed under A1: Direct Habitat Loss & Habitat Fragmentation, above.

- Oysterfarming racks displace feeding areas of some shorebird species but only the actual ground covered, or between them if they are less than about 10 metres apart.

- Determine the maximum feeding area displaced by oyster-farming structures by calculating the surface area of the racks and add any interstitial areas less than 10m wide. For Eastern Curlew and Whimbrel, the surface area of the racks only need be applied, and for Tattler, only the area of racks solidly covered, less than 200mm high and/or with solid walls.

- Consider the ground cover created by oyster growth on shellbanks, aerial roots, rocks and rock platforms, and oysterfarming racks to contribute to the feeding and roosting habitat of Tattlers.

- Balance Tattler habitat conservation with that of shorebird species which use more open habitats. Conflicts of interest are unlikely at the levels of mangrove or seagrass cover nominated in the guidelines, and there can be overlap in habitat use (eg. Pacific Golden

Plover use shellbanks, Tattler use open seagrass beds), but some areas may need to be managed with the habitat needs of Tattler a priority over those of other species.

- Maintain cover of oysters, rocks, mangrove aerial roots, macroalgae, seagrass and/or mangrove seedlings on areas selected for Tattler conservation (See discussion of mangrove seedlings under A8: Vegetation Cover, above).

- Avoid oysterfarming racks which are too low for Tattlers to feed under (<200mm high) and which have solid covers, if these cover large areas. Also avoid constructing racks with solid vertical walls which block shorebird visibility.

A10: Changes to Water Level (27):

- Changes to water level of intertidal areas will also affect tidal regime (see A6: Tidal Regime) and elevation profile (see (C) Elevation Profile below).

- Distinguish natural changes from human induced changes. Natural changes, such as in coastal lagoons in wet or dry periods, are beyond normal management objectives (maintaining natural systems). A strong case for manipulation for shorebirds over other values would be needed before interference was justified.

- For feeding shorebirds, wet or very shallow (<50mm deep) ground is best, so avoid changes to water level which reduce this habitat. However, wet areas need water level fluctuations, either tidal or manipulated, adequate to flush excess salinity and maintain wetness and invertebrate populations (see below).

- Generally, avoid human induced water level changes to natural intertidal areas of high conservation value to shorebirds. Remove or mitigate against human-induced depositions which block intertidal areas, and provide access for natural tidal flow. See A6: Tidal Regime, above, for discussion of artificially manipulated intertidal areas.

- Coastal lagoons (45% of 'estuaries' in New South Wales) naturally connect intermittantly with the sea. Shorebird habitat in coastal lagoons may be enhanced by breaches which decrease water level and increase the area of wet and shallowly inundated flats, but these breaches have other affects on the wetland, such as major fluctuations in salinity (see D3: Salinity, below). Such reductions in water level have been known to kill seagrass beds and fish, so management of such openings for shorebirds needs careful balancing with other conservation and resource management priorities.

- Protect wetlands above mean high tide level (saltmarsh, brackish or freshwater wetlands) from (i) prolonged or permanent drying, or, for saltmarsh, rapid draining, and (ii) permanent or prolonged deep flooding. Shorebirds benefit from such wetlands if they have water level changes which provide a changing mozaic of wet and shallow areas, each of which has medium term (weeks to months) cycles of shallow flooding (>200mm<1m) and exposure (wet to <150mm). Overseas information indicates periods of shallow inundation allow invertebrates to increase (see *Further Reading: Wetland Construction & Manipulation*).

(A) Size, Shape and Position (cont.)

- An allied subject is mosquito control in urban wetlands. Runnelling and ditching are traditional methods of limiting mosquito larvae habitat in saltmarsh and brackish water wetlands, but drain potential shorebird habitat. 'Open Marsh Water Management' which involves constructing tide-fed pools and wider channels which provide refuge habitat for fish (mosquito larvae predators), is gaining acceptance overseas as an ecologically preferable and more effective mosquito control.

  Works of this type can minimise loss of shorebird habitat in above-mean-high-tide wetlands subject to mosquito management, provided pools and channels have large enough shallow margins. Conversion of drained or runnelled saltmarsh to Open Marsh Water Management by adding fish pools can enhance previously lost shorebird habitat while maintaining or improving mosquito control. See *Further Reading:Mosquito Management.*

(B) Vegetation

Habitat attributes: % Surrounding Mangrove; % Adjoining Mangrove; % Mangrove Cover; % Total Ground Cover.

Impacts to Manage:

B1: Mangrove Loss (3):

- Consider shorebird conservation as one of the important reasons for mangrove conservation, both for the contribution of mangroves to feeding area fecundity, and as high tide roosts for some species (Whimbrel, Tattler, Terek and Common Sandpiper and others) - particularly mature mangrove trees with spreading, open lower limbs (see Chapter 6: Roosting Habitat).

- Follow and enforce laws and bylaws aimed at mangrove protection (eg. NSW Fisheries Management Act 1994).

- Strictly adhere to requirements of SEPP 14 and protected area management plans, and view critically development proposals which involve removal or endanger fringing mangroves.

- Monitor developments and resource use during and after implementation to ensure mangrove protection and health, and take appropriate action (see relevant impacts below). Require restoration of affected areas.

- These principles also apply to other species of fringing trees such as *Casaurina* in brackish water wetlands.

B2: Seagrass Loss (4):

- As a source of organic matter contributing to plant and invertebrate abundance, a stabiliser of erosion and deposition, and as a component of ground cover, consider seagrass a shorebird habitat attribute to be managed, as well as an important component of the estuarine environment.

- Avoid dredging, extraction or reclamation work which will reduce seagrass area.

- Avoid physical damage to seagrass beds from trawling and dredging fishing operations, and boating (propellor and anchor chain damage).

- Mitigate against erosion and deposition, pollution and unnatural increases in turbidity which endanger seagrass beds (see B4: Erosion & Deposition, B8: Nutrients, B12: Turbidity and B13: Algae).

B3: Loss of Fringing Vegetation (5):

- Adhere to and enforce laws, bylaws and management plans aimed at preserving littoral and foreshore vegetation.

- Maintain foreshore vegetation buffers 100+m wide wherever possible (minimum 30m), and protect vegetation on steep catchment and foreshore slopes.

- Incorporate adequate buffer requirements into development proposals and ensure that the buffer requirements are costed as true buffers and not as areas for multi-purpose or future development uses which are incompatible with their function as buffers.

- Remember the primary functions of a foreshore buffer around shorebird feeding areas are (i) filtration and slowing of sediment rich runoff, (ii) maintenance of organic matter input, (iii) physical and visual screen from disturbance, and (iv) protection of fringing mangroves and shorelines.

B4: Erosion and Deposition (6):

- Mitigate against erosion and deposition which endangers intertidal vegetation, such as deposition on seagrass beds or erosion of mangrove fringed banks (see A2: Erosion and Deposition, above, (C) Elevation Profile, below).

- Restrict boat speed where wash is undermining mangrove trees (see A7: Wave Climate and Wave Action, above).

- Removal of vegetation may be necessary in extreme cases of colonisation of accreting areas which are building on shorebird feeding areas of high conservation value (see A9: Vegetation Cover, above).

(B) Vegetation (cont.)

B5: Salinity Changes (13):

- Estuarine flora and fauna are adapted to fluctuations in salinity. It is the salinity regime or normal range of salinities, roughly expressable by a mean salinity, which needs to be protected. An analogy is climate which, rather than the day to day weather, normally dictates vegetation. However, brief but extreme departures from the salinity regime (eg. flood) can affect vegetation and invertebrate abundance.

- Salinity regime profoundly affects the type of vegetation community in a wetland and therefore the nature of the wetland. It also affects invertebrate species and relative abundances. Approximate soil salinity, the important factor, by water salinity. Salinity above seawater caused by evaporation (areas above mean high tide or tide-restricted areas with no freshwater inflow) supports salt-tolerant shrubs/forbs (eg. *Sarcocornia*) or if extreme, no vegetation; the normal range of estuarine salinities support seagrasses, algae and mangroves below high tide (see Section 2: Vegetation Cover (25)), and mangrove, sedge and rush (eg.*Juncus*), shrubs/forbs and saltcouch meadow (*Sporobolus*) above. Brackish wetlands typically support algae, sedges, rushes, reeds and *Casaurina*.

  Avoid major and sudden changes of salinity regime which may kill the vegetation without it being quickly replaced by plants adapted to the new conditions (see below, and A10: Water Level, D3: Salinity Changes). Shorebirds, via invertebrates, may suffer (see Section 2: Organic Matter (22) and C7: Invertebrates, below). Estuarine invertebrates are generally less abundant in salinities above seawater (about 37 g/L or more), and species changes occur in low salinity (about 10g/L or less).

- Avoid or stop changes to wetland salinity regimes if present wetland vegetation (and invertebrate fauna) is to be preserved, and be aware of effects salinity changes will make (see also A6; B6: Tidal Regime).

- If salinity regime changes are suspected, monitor water salinity (taste) or conductivity (simple and relatively inexpensive instruments). See Appendiix II for instrument and sampling considerations.

- Criteria in Chapter 2 are based on the shorebird use of intertidal flats of a range of salinities rather than vegetation tolerance. Grey Mangrove *Avicennia marina* can die at a water salinity of 50g/L (seawater 35-37g/L) if resultant soil salinity is high. They will grow in brackish or even fresh water but are usually out-competed.

- If continuous effluent outflows are affecting salinity regime reduce flow rates on incoming tides, particularly the bottom half of the incomimg tide, and low tide. Compensate if necessary by increasing flow rates on the top half of the outgoing tide. Avoid outfalls into areas of restricted tidal access.

- Salinity regime of naturally fresh wetlands can be altered by intrusion of seawater, eg. through removal of a floodgate, excavation of a drainage canal, or breaching or overtopping of a levee or wall. Avoid intrusion of tidal water into freshwater wetlands if the maintenance of the freshwater wetland is the aim.

- Most peripheral estuarine wetlands are adapted to some salinity, eg. saline soils, intrusion of seawater on king tides. Impact of seawater intrusion depends on volume of intrusion, volume of waterbody or volume of freshwater inflow, and frequency. With substantial shifts toward a more saline regime, changes may be: replacement of submerged and floating aquatic vascular plants ('water weed', 'lilies') with algae, dieback of common reed *Phragmites*, sedges eg. *Baumea* or cumbungi *Typha*, dieback of *Polygonum* and other freshwater fringing growth, increases in rushes eg. *Juncus* and or 'saltcouch' *Sporobolus*, development of bare littoral areas, death of *Melaleuca* trees and colonisation by halophytes (eg. *Sarcocornia*).

  Effects on shorebird feeding habitat quality are difficult to predict (see A10: Water Levels, above; D3: Salinity Changes, below) but shorebird habitat may be enhanced at the cost of other groups such as rails or passerines, and possibly snipe.

B6: Changes to Tidal Regime (15):

- Take actions listed under A6: Changes to Tidal Regime, above.

- Ensure natural tidal regime is preserved sufficiently to maintain conditions under which vegetation can survive and propagate with natural levels of success (not just survive).

- Be aware of likely changes to wetland vegetation if tidal regime is changed (eg. by blockage). See B5: Changes to Salinity, above.

- Assume any major blockage of tide flow will eventually kill or degrade tidal vegetation, leaving an area difficult to restore (see B14: Vegetation Cover, below).

B7: Changes to Wave Climate and Wave Action (16):

- Protect against increased wave action which may erode seagrass beds or fringing mangrove (see A2, B4: Erosion & Deposition, above) or increase water turbidity (see D6: Turbidity, below), by boat speed restriction, maintenance of shore and bottom shape, provision of wave breaks etc where appropriate.

- Monitor or require monitoring of germination rates of seagrass or mangrove in areas of increased wave action. Survival of established plants does not mean rates of replacement or increase are not affected.

- Monitor or require monitoring of rates of mangrove germination and cover increase in areas of decreased wave action (eg. behind walls, restrictions) which may lead to decreased shorebird feeding areas (see guidelines, Chapter 2, A8: Vegetation Cover, above).

- Control bank erosion affecting fringing mangrove (see B4: Erosion & Depostion, A7: Wave Climate & Wave Action, above).

(B) Vegetation (cont.)

B8: Nutrients Changes (18):

- Ensure excessive, unnatural sources of nutrients in estuaries are minimised and consider increased nutrient levels a potential cause of change to estuarine vegetation, particularly seagrass and algae, which may impact shorebird feeding directly through displacement of feeding space or changed habitat and toxicity, or indirectly by changing invertebrate fauna. See also D5: Nutrients, below.

- Attribute sudden changes to algal growth to unnatural increases in nitrogen and/or phosporus inflow.

- Identify sources, or potential sources in proposals, of nitrogen and phosphorus entering the estuary, eg. industrial effluent, sewage outfall, catchment flow, groundwater and seawater drifts, and manage these sources (see D5: Nutrients, below).

- Require hydrological studies, including studies of circulation and water exchange, as part of any proposal which may be a source of nutrients affecting vegetation.

- Avoid reductions to circulation and water exchange (see A2: Erosion & Deposition, A6, B6: Tidal Regime, above) and reduction in salinity (see B11: Algae, below).

- Consider that increased levels of nutrients below that which causes a decline in general productivity can benefit some species of shorebirds (via increases in some species of invertebrates) though sometimes at the expense of other species, and balance shorebird conservation among species, and with that of other estuarine values eg. seagrass, fish. The common aim of estuarine management is to maintain natural ecosystems. (See Section 2 (18): Nutrient Changes, and B13:Algae, D5: Nutrients, below.)

  The balance may be at the point where the ratio of discharge to estuary volume and flow provides sufficient transportation and predation of phytoplankton (which make nutrients available to larger plants) to prevent a build up of their wastes,and consequently plant growth (eg. macroalgae), outstripping aerobic decomposition. Once this occurs, dissolved oxygen decreases and invertebrate populations decline.

B9: Decrease in Dissolved Oxygen (19):

- Ensure estuarine wetland management or development/resource use proposals do not lead to anaerobic water conditions, such as caused by tidal restrictions (see A6, B6: Tidal Regime), nutrient inflow (B8, D5: Nutrients) or algal blooms (see B12: Algae, below).

B10: Toxicity to Vegetation (and Invertebrates) (20):

- Ensure conditions leading to toxic or obnoxious algal blooms are not created (see B12: Algae, below).

- Avoid disturbance to acid sulphate soils, contain runoff from any such disturbance, and monitor pH levels where risk of acid runoff exists.

- Apply pollution guidelines and regulations in co-operation with pollution control authorities (eg. Environment Protection Authority), to present and future industrial and urban development. Consider that existing criteria for safe pollution levels may not be adequate for long-term shorebird conservation (see discussion on sub-lethal levels in D6: Toxicity to Shorebirds).

- Identify shorebird feeding areas and vegetation (eg. mangrove fringes) for special consideration in oil spill contingency plans.

- Monitor levels of pesticides, heavy metals and petroleum hydrocarbons in water, sediment and invertebrates at point sources (industrial effluent, sewage and urban stormwater outfalls), harbours, ports and canal estate mouths, creek and drainage canal mouths draining agricultural land, and near leaching sites (landfill, rubbish tips) which are likely to affect very high conservation value shorebird feeding areas (see also D6: Toxicity to Shorebirds, below).

B11: Changes to Organic Matter (22):

- Consider changes to erosion and deposition (A2, B4: Erosion and Deposition, above) and loss of vegetation (B1-B3, above) potential long-term causes of lower organic matter which may affect vegetation, particularly pioneering vegetation, invertebrates and indirectly shorebirds. Apply strategies listed under these headings.

- Ensure any loss of intertidal and other wetland vegetation is replaced by plantings, and include such requirements in new proposals (see *Further Reading: Wetland Construction & Manipulation* for SPCC/NSW Fisheries guidelines). Mangrove plantings have become an important component of estuarine wetland productivity restoration in tropical and subtropical parts of the world.

B12: Turbidity Changes (23):

- Manage sedimentation (see A2, B4: Erosion & Deposition, above) and algal growth (see B8, D5: Nutrients, and B13: Algae) to control turbidity detrimental to seagrass growth.

B13: Algae (24):

- Avoid increases in nutrient (nitrogen, phosphorus) inflows into estuaries (see B8, D5: Nutrients).

- Determine if excessive macroalgal (seaweed) growth on intertidal flats is reducing availability of shorebird feeding area, and consider other conservation priorities (eg. maintenance of macroalgal species richness, reduction of rotting seaweed on beaches).

- Control, if required, excessive macroalgae by physical removal and/or management of nutrient levels (see D5: Nutrients, below).

(B) Vegetation (cont.)

- Determine if excessive epiphytic algae on seagrass is causing seagrass dieback by blocking light to leaves, and if so control causes, potentially excessive nutrients.

- Avoid conditions conducive to blue-green algal blooms: reductions in salinity below 15g/L at water temperatures above 18°C and high nutrient levels and inputs.

- Control blue-green blooms by increasing salinity above 30g/L if possible, increasing circulation and removing source of nutrients.

- Avoid reductions in water circulation and water exchange (see A2: Erosion and Deposition, A6, B6: Tidal Regime, above).

B14: Change to Vegetation Cover (25):

- Be aware that apart from direct effects of vegetation loss (see all impacts in this section), change in vegetation cover can have a direct effect on further vegetation loss. Seagrass canopy (leaf blades) protect roots from wave and current action. Loss of seagrass canopy cover, eg. from excessive algal growth, exposes plants to wave and current caused abrasion and erosion, thus continuing vegetation loss.

- Loss of mangroves (see B1: Mangrove Loss, above) or foreshore trees (see B2: Loss of Fringing Vegetation, above) can expose other vegetation to salt-laden winds or erosion, causing further loss. Apply strategies listed in these headings.

- Loss of tall mangroves can cause germination of denser ground cover, displacing shorebird feeding habitat under tall canopy. Protect mature mangrove trees (which are also shorebird roost trees). Apply strategies listed under B1: Mangrove Loss, B3: Loss of Fringing Vegetation, above).

B15: Changes to Water Level (27):

- Avoid changes to water level regime which will inundate mangrove aerial roots permanently or for long periods (weeks or more).

- Avoid changes which will increase durations of seagrass exposure (tidally).

- Avoid flooding or drying peripheral (above mean high tide) wetlands for long periods during shorebird season, or permanently.

- See discussion of water level management under A10 : Water Level, above.

(C) Substrate Type and Elevation Profile

Habitat attributes: Mean Surface Hardness; % Dry Ground at Low Tide; % Wet Ground at Low Tide; % Shallow Ground at Low Tide; % 50-150mm Deep Ground at Low Tide; Secchi Transparency.

Impacts to Manage:

C1: Direct Habitat Loss (1), Habitat Fragmentation (2):

- Consider changes to elevation which raise intertidal flat surfaces so they are high and dry at low tide, or lower levels to below about 100mm deep on mean low tide, to be reducing shorebird feeding habitat. Apply strategies under A1: Direct Habitat Loss, Habitat Fragmentation, above. See also C3: Erosion & Deposition, below. Use estimates of proportions, or levels (Chapter 2). See Appendix II for evaluation techniques.
- Maintain small areas of high elevation which are used as 'staging' or transitory mid-tide or neap high tide roosting areas.

C2: Seagrass Loss (4):

- Seagrass dieback exposes intertidal areas to erosion leading to changes in elevation and substrate type. Protect seagrass by strategies listed under (B) Vegetation, above.

C3: Erosion and Deposition (6):

- Avoid changes to estuaries which may cause or change erosion and deposition patterns, and apply strategies in A2: Erosion & Deposition, above to existing problems and proposed works.
- Monitor substrate type on problem areas to ensure marine (or catchment) sand of low organic content (texture class 'Sand' - see Appendix II) is not burying more productive substrate types.
- Monitor elevation profile on areas susceptable to erosion and deposition either visually at low tide (estimating proportions of dry, wet, shallow ground etc - see Appendix II) or with surveyors level using datum and levels in Chapter 2.
- Where shorebird feeding habitat is shown to be degraded, undertake or require restoration work. Successful restoration has resulted overseas from removal of material to suitable levels on intertidal areas which had built up through deposition. Islands can be easily incorporated for roosting. Use specifications in Chapter 2 (Table 2.19) or levels in Fig.2.9.

(C) Substrate Type and Elevation Profile (cont.)

C4: Changes to Soil Texture (7):

- Control deposition of sand (see C3: Erosion & Deposition, above), and encourage or plant vegetation (see B14: Vegetation Cover, above) or increase silt/clay/organic content on areas of former high conservation value for estuarine shorebirds degraded by sand deposition.

- Note that 'Loamy Sand', an acceptable soil texture for shorebird habitat, looks very similar to pure sand. Apply simple texture assessment procedures in Appendix II. Also note that texture preferences of beach-frequenting shorebirds (eg. Hooded Plover, Sanderlings) and their prey were not included in the study. Maintenance of the natural soil texture is the best management strategy unless working to a specific shorebird conservation goal.

C5: Changes to Shape, Shoreline Length and Position (9):

- Ensure changes in the shape of intertidal areas do not reduce shoreline length and/or the proportion of wet or very shallow (<50mm deep) ground at low tide. Compensate for such changes by increasing such areas.

- Monitor elevation profile after the relative position of an intertidal area in relation to open water is changed. For example, an area enclosed by development may increase in elevation through deposition; areas exposed more by excavations or dredging may erode or become sandier through increased wave action washing away fine sediments. Mitigate against these changes (see (A) Size, Shape & Position, above).

C6: Changes to Roughness (11):

- Another aspect of change by erosion or deposition, roughness or bumpiness of the flat surface (microrelief) can effect elevation profile. Very humped topography can reduce the area of wet and shallow ground. Apply strategies under C1 and C3 above.

- Avoid extreme mechanical alterations to roughness, such as excavations, pugging and bait collecting, which radically increase relief. There was no relationship between shorebird numbers and lumpiness caused by normal levels of bait collection during the study (see C7: Invertebrates below for other aspects of bait collecting).

C7: Changes to Invertebrates (14):

- Soil-dwelling animals - worms, molluscs, crabs and many others - are the food of shorebirds, and their abundance and mix of species directly affects shorebird well-being. Abundance and mix of species can also indicate pollutants. Tidal regime on the microhabitat scale, expressed by elevation profile, and organic content, expressed by substrate type, dictates invertebrate fauna to a large degree.

  The use of invertebrate populations to assess, monitor and manage shorebird feeding habitat is ecologically sound but as yet not well developed.

- Use the shorebird feeding habitat managemen stategies in this thesis as an approximation of shorebird prey management (see discussion of this in Chapter 5 and in Section 2 (14): Invertebrates).

- Monitor invertebrates as part of impact and recovery assessment of pollution, and changes in salinity, tidal regime, sedimentation and water level.

- Monitor invertebrates to assess impact of bait collecting and invertebrate food harvesting, and other extractive resource use.

- Monitor bait collectors - numbers, frequency, catches. A survey can be designed which can provide management information such as types of invertebrates taken, quantities (and trends, such as a decline in one or more types), social groups involved, conditions and times under which high take-offs occur (eg. low tide in the middle of the day, weekends, sunny weather). Develop management plans and education based on such surveys.

- Apply and enforce regulations to invertebrate harvesting in areas of high conservation value to feeding shorebirds, where effort is concentrated and found, by monitoring either invertebrates or bait collectors' takings, to be excessive (unsustainable), or found by invertebrate monitoring to be degrading shorebird food supply.

- Concentrate invertebrate monitoring on trends in abundance of likely important shorebird prey items such as common varieties of worms, soft-shelled molluscs, amphipods, isopods, shrimps and small crabs. Identify to species if possible, but at least note changes at the level of identifiable variety eg. worm type A, B etc. Some species may be more valuable to shorebirds than others due to behaviour (catchability), reproductive rate, food value.

- Use carefully planned and designed sampling programmes when investigating changes to invertebrate abundance and species. Invertebrates typically have variable patterns of distribution within and between areas and simple sampling designs (intuitive, informal or one-off) are not adequate. Before and after sampling and control (or reference) locations are needed to test for an impact. Consult an experienced researcher and consider the 10 principles in Green (1979) (see *Further Reading*).

C8: Changes to Tidal Regime (15):

- Avoid restrictions to tidal regime which reduce durations of exposure at low tide and increase water levels. Avoid restrictions that leave intertidal areas exposed, or flooded for short durations, at high tide. See A6,B6: Tidal Regime, and A10, B15: Water Levels, above.

- Monitor changes to elevation and high and low tide water levels in areas where tide is restricted, and maintain adequate elevations in relation to low tide (Chapter 2) by strategies listed in A6 & B6: Tidal Regimes, above.

(C) Substrate Type and Elevation Profile (cont.)

C9: Changes to Wave Climate and Wave Action (16):

- Manage wave action as a component of erosion and deposition, on both the large scale (estuary wide) and small scale (effects on flats). See C3: Erosion & Deposition, C5: Shape, Shoreline Length & Position. Apply strategies in A2: Erosion & Deposition, A7: Wave Climate & Wave Action.

C10: Changes to Turbidity (23):

- Monitor elevation profiles in areas of increased turbidity and sedimentation and apply strategies in A2: Erosion & Deposition, C1: Direct Habitat Loss and C3: Erosion & Deposition, above.

C11: Changes to Vegetation Cover (25):

- Substrate type and elevation profile are affected by vegetation as described under C2: Seagrass Loss, above, and by sediment trapping by mangrove. Protect seagrass (see (B) Vegetation, above) and monitor elevation increases in areas of mangrove increase. See C1: Direct Habitat Loss, C3: Erosion & Deposition, above, and Chapters 2 and Appendix II for criteria.

C12: Cover by Structures (26):

- Structures can trap sediments in the same way as mangroves (C11 above). Avoid structures which offer large surface areas to prevailing currents and wave action. Avoid oysterfarming racks with solid walls.

- Monitor elevation and substrate type around structures on intertidal areas and restore or require restoration to appropriate levels and texture types if required (see C1: Direct Habitat Loss, C3: Erosion & Deposition, above), on areas of high (or formerly high) conservation value to shorebirds.

C13: Changes to Water Levels (27):

- Avoid or intervene in water level changes which artificially reduce water levels so intertidal or other shorebird feeding areas are exposed permanently or for long periods (relatively in tidal areas, or for weeks to months during shorebird season in non-tidal areas).

- Avoid or intervene in water level changes which artificially flood intertidal or other shorebird feeding areas permanently or for long periods, to a depth over about 100mm.

- Maintain feeding areas at wet or very shallow elevations during low tide or during shorebird season in non-tidal wetlands where migratory shorebird habitat provision is a priority. See discussion of water level manipulation in A6, B6: Tidal Regime and A10, B15: Water Levels, above.

(D) Water Properties (and Pollutants)

Habitat attributes: Mean Salinity (conductivity); Secchi Transparency; Orthophosphate.

Impacts to Manage:

D1: Erosion and Deposition (6):

- Avoid or control erosion and sediment inflow which is creating water sediment loads either harmful in content (eg. low pH from disturbed acid soils, polluted) or which create excessive turbidity harmful to seagrass. Note that shorebird feeding habitat can benefit from levels of turbidity above that tolerated by seagrass, so shorebird conservation needs to be balanced with conservation of other estuarine values. Apply strategies in A2: Erosion & Deposition, above.

- Counter (eg. by groynes) changes to the estuary mouth or channel (erosion or works/ dredging) which decreases the long-term turbidity regime of water over shorebird feeding areas of high conservation value (see D8: Turbidity, below).

D2: Changes to Shape, Shoreline Length and Position (9):

- Monitor changes to salinity, turbidity and nutrient levels of water associated with flats affected by works reducing the relative position of the flat in relation to open water. Use criteria in Chapter 2 (Table 2.19) and apply strategies under A6: Tidal Regime, B8, D5: Nutrients and D6: Toxicity.

D3: Changes to Salinity (13):

- Regard long term (weeks to months) changes to salinity regime as a water property to manage and minimise, rather than short term (tidal or days to weeks) fluctuations. This is because protection of wetland ecology is needed rather than a prescribed salinity value for shorebirds, which are dependent on salinity indirectly through prey availability.

- Manage salinity regimes according to the desired wetland vegetation community (see B5: Salinity, above). Generally, maintain the natural salinity regime of wetlands - either intertidal and saltmarsh, brackish with natural fluctuations (eg. seawater inflow on king tides or after breaching of the mouth) or strictly fresh.

- Decisions to change wetland salinity regimes should be based on regional or species conservation priorities, or restoration to former natural regimes in keeping with these conservation priorities. Balance shorebird conservation with other wetland values.

- Within the considerations above, maintain mean salinities of tidal wetlands within the guidelines in Chapter 2 according to the species concerned.

(D) Water Properties (and Pollutants) (cont.)

- Avoid unnatural changes to estuary mouths and intertidal areas (constructions restricting tides) which cause salinity to frequently exceed these limits. This will need application of stategies dealing with developments (A1: Direct Habitat Loss, Fragmentation), erosion and deposition (A2: Erosion and Deposition), effluent (B8, D5: Nutrients), and tidal regime (A6, B6: Tidal Regime). See also B5: Salinity.

- Intermittantly opening coastal lagoons vary in salinity with rainfall and evaporation, sometimes increasing in salinity with rainfall because high water levels breach mouth deposits built up in times of no flow, thereby connecting the lagoon with the sea. Fluctuations range from brackish (about 6g/L) to nearly seawater (about 33g/L), so lie within the guidelines (Chapter 2, Table 2.19), for most shorebird species (although such salinity fluctuations affect other aspects of lagoon ecology much more). Water level fluctuations have a more direct effect on shorebird habitat in these lagoons (see A10: Water Level, above).

D4: Changes to Tidal Regime (15):

- Avoid tidal restrictions (see A6: Tidal Regime, above) in naturally tidal areas and require, in addition to other studies, the modelling of salinity and nutrient regimes in E.I.S.'s of potentially affected areas.

- Require monitoring of salinities and nutrient levels (see Chapter 2) in intertidal areas of restricted tide access, circulation and/or water exchange, including canal developments. Ensure developments have effective long term monitoring programmes and water quality management facilities costed in to the project.

- Manage inflows into existing restricted intertidal areas to ensure salinity regimes do not change and nutrient levels do not become excessive (see D5: Nutrients, below). Avoid effluent or stormwater discharge into areas of restricted tidal flow, circulation and water exchange.

D5: Nutrients Changes (18):

- Apply regulations and pollution control requirements to proposals likely to contribute nutrients to estuarine waters, and ensure E.I.S.'s include nutrient management.

- Manage affected areas by (i) measuring nitrogen and phosphorus levels to determine extent and level of enrichment, and which nutrient is naturally limiting in the estuary, (ii) determining hydrology (tidal, catchment and wind induced currents, water exchange), and (iii) determining objectives and level of management necessary and feasible, in conjunction with pollution control authorities.

- Identify point sources of nutrients (nitrogen and phosphorus) such as sewage outfalls, industrial and intensive agriculture effluent, stormwater outlets, canal estates and drainage canal outlets.

- Control point sources of nutrients. For example, (i) install scrubbers and other processing technology to minimise release of nitrogen from industrial processes, (ii) use artificial wetlands for tertiary sewage treatment, industrial wastewater treatment and urban stormwater drainage, (iii) use deepwater outfalls rather than estuarine sites, (iv) ensure adequate tidal flush and time releases for the top of outgoing tides.

- Minimise diffuse inflow of nutrients in catchment flows and groundwater by appropriate catchment management: (i) minimise clearing and erosion of catchments, including sandy coastal lowlands and encourage re-afforestation, (ii) avoid drainage works in coastal lowlands, (ii) monitor superphosphate levels in pastoral land and fertiliser in agricultural land and only use amounts needed (in co-operation with agricultural authority and farmers), (iii) use slow-release superphosphate, especially in sandy coastal lowlands.

- Avoid tidal restrictions (see A2: Erosion & Deposition, A6, B6: Tidal Regime, above).
- Keep in mind that, within limits, many shorebird species benefit more from increased nutrient levels than some other estuarine organisms (eg. seagrass and seagrass dependent species), including artificial nutrient increases. For shorebird conservation, the balance between nutrient limitation and excessive nutrients leading to decline is probably further along the gradient of increasing nutrient levels than it is for the conservation other estuarine values. Management, for some shorebird species at least, consists of recognising the point at which enrichment reduces prey, and controlling levels below this point (see B8:Nutrients; C7: Invertebrates, above).

D6: Toxicity (to Shorebirds) (20):

- See B10: Toxicity (to vegetation) and apply strategies listed there. Also apply strategies for nutrient pollution in B8, D5: Nutrients, above.

- Based on recorded contamination of estuary birds in the literature, include in pollution assessment and control requirements :
  Pesticides: polychlorinated biphenyl, DDT, dieldrin, organophosphates, carbomates;
  Petroleum Hydrocarbons (n-C_{15}+): chlorinated hydrocarbons, aromatic (halogenated, polynuclear) hydrocarbons, saturated hydrocarbons, n-alkane;
  Heavy metals and organic metal compounds: arsenic, cadmium, chromium, lead, mercury, selenium, zinc;
  Other chemicals: sulphides, soluble flouride,
  Bacteria.

- Co-operate with pollution control authorities (eg. Environment Protection Authority) in the identification of shorebird feeding areas of high conservation value, the setting up of investigations, monitoring programmes and contingency plans, and the enforcement of pollution laws.

- Ensure proposals for industrial, agricultural or urban development, or waste and solid fill disposal, meet pollution guidelines and facilities and commitment exists for continuing pollution control.

(D) Water Properties (and Pollutants) (cont.)

- Avoid use of oil spill dispersants which have been found toxic to marine invertebrates and seabirds.

- Include groundwater quality in pollution control and assessment because groundwater enters estuarine systems, often diffusely.

- Consider so-called sub-lethal doses potentially lethal when assessing environmental or tissue pollutant levels. Relatively low levels of pesticide, oil and selenium have been shown to cause increased susceptibility to disease in ducks and could reduce fitness thus increasing predation or other natural mortality, or reproductive success (see *Further Reading: Nutrients, Pollution & Disease*. References contain some level values).

- Because of the biomagnification potential of many pollutants, monitoring of benthic invertebrate tissue for contaminants may provide a much more realistic estimate of pollution level than sampling the environment. A study in the Brisbane River estuary identified ingestion of contaminated invertebrates as a much greater source of petroleum hydrocarbons in estuary birds than ingestion of water, and comparatively high levels of these pollutants in bird muscle tissue despite low levels in the water and sediment (see *Further Reading: Nutrients, Pollution & Disease*).

D7: Changes to Turbidity (23):

- Preserve the turbidity regime of estuarine waters, which determine the long-term sedimentation regime of intertidal areas. This involves maintaining wave and current patterns (see A7: Wave Climate & Wave Action, A2: Erosion & Deposition, above), tidal regime and circulation (A6: Tidal Regime), and catchment flows and sediment loads (A2: Erosion & Deposition, B3: Loss of Fringing Vegetation, B4: Erosion & Deposition).

- Some species (Whimbrel and Greenshank), and species number of shorebirds, are linked in this study to sediment rich habitat. Avoid long term increases in the extent and volume of seawater intrusion on high tide, for example by channel improvement at the mouth, which might reduce the sediment regime on intertidal flats.

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