6.1.2. Habitat Areas of Conservation Significance

Threatened fauna often require specific habitats or a combination of specific habitat types. Any habitat essential to the life cycle of a threatened species may, therefore, be of conservation significance. Specific habitat types may also have legislative protection. The TSC Act lists a number of floodplain vegetation communities as Endangered Ecological Communities (EEC). State Environmental Planning Policy (SEPP) 14 Coastal Wetlands and SEPP 26 Littoral Rainforests are also mapped for conservation purposes. Many habitat areas of the Macleay floodplain have legislative protection of some form. The EECs and SEPP 14 wetlands are considered further in this report. Many floodplain fauna are dependent upon specific wetland habitats to complete major components of their life cycle, such as breeding.

Seven different wetland types have been mapped under SEPP 14 – Coastal Wetlands: mangroves, saltmarshes, Melaleuca forests, Casuarina forests, sedgelands, brackish and freshwater swamp, and wet meadows. However, a number of other groundwater-dependent ecosystems were omitted from SEPP 14. Recently, a number of these communities were listed as EECs under the TSC Act (the most relevant being Coastal Saltmarsh and Freshwater Wetlands on Coastal Floodplains, Subtropical Coastal Floodplain Forest, Swamp Sclerophyll Forest on Coastal Floodplains, Swamp Oak Floodplain Forest and River-flat Eucalypt Forest). The wetland types considered important to threatened and migratory species are mangroves, saltmarshes, sedgelands, brackish and freshwater swamp and wet meadows.

In estuaries and on floodplains, the frequency and duration of inundation, substrate type, and salinity are the major determinants of wetland type (Goodrick 1970; Davis *et al.* 2001; Peirson *et al.* 2002). Wetland boundaries can change in response to variation in the amount of rainfall, which affects water levels. In estuarine habitats, the frequency and extent of tidal inundation are also important determinants of habitat type. In coastal catchments, floods represent extreme but short-lived increases in water levels.

Thirteen major areas of habitat were identified on the Macleay floodplain, as shown in Table 39. Only three significant wetland areas were identified on the upper floodplain (corresponding to Zone C of ID Landscape Management 2005). Two of these were the only substantial billabongs in the study area. The freshwater wetland/fresh meadow on upper Christmas Creek is smaller than similar habitats in the mid section of the floodplain.

Table 39 Significant Areas for Significant Fauna on the Macleay Floodplain

"Zone" refers to the division of the Macleay floodplain as defined by ID Landscape Management (2005, Plan 1).

Area	Zone	Significance
Christmas Creek (north of Kempsey)	C	Freshwater wetland on upper floodplain
Barnetts Lagoon	C	Billabong on upper floodplain
Old Pola Creek	C	Billabong on upper floodplain
Cooroobongatti Swamp	B	Freshwater wetland on mid floodplain
Swamp W & SW Clybucca	B	Freshwater wetland on mid floodplain
Swamp NE Kinchela	B	Freshwater wetland on mid floodplain
Swamp SE Kinchela	B	Freshwater wetland on mid floodplain
Swamp S Jerseyville	B	Freshwater wetland on lower floodplain
Clybucca Creek	A	Tidal Channel, saltmarsh / wetland
Andersons Inlet	A	Tidal Channel,
Pelican Island	A	Saltmarsh / wetland
N of Rainbow Beach (b't river & Clybucca Ck)	A	Saltmarsh / wetland
Shark Island & adjacent channels	A	Tidal Channel, saltmarsh, extensive mudflats

Five freshwater wetlands/fresh meadows were identified on the mid floodplain (corresponding to Zone B of ID Landscape Management 2005). Four of these are large freshwater wetlands/fresh meadows. The swamp south of Jerseyville is relatively small, but it occurs in close proximity to other wetlands (i.e. the wetland north-east of Kinchela). While these wetlands are predominantly fresh, there is likely to be some brackish influence resulting in areas of saltmarsh. In the middle section of the study area the Macleay River channel is beginning to broaden and small intertidal flats have developed.

The lower floodplain (corresponding to Zone A of ID Landscape Management 2005) has substantial areas of wetland and it is only possible to document the most significant of these. Infilling of the estuary has resulted in the formation of a delta, with the resulting formation of islands (e.g. Pelican Island, Shark Island), which have extensive areas of intertidal flats around their margins. The landward communities of the estuary are comprised mainly of mangroves and saltmarsh.

6.1.3. Flooding and the Ecology of Significant Floodplain Fauna

Rainfall in Australia is highly variable. Many Australian catchments experience intense rainfall events that result in flooding. Floods may have both positive and negative effects on wetland fauna. However, the precise impact of flooding is determined by a number of factors. These include the extent, duration, frequency and season of flooding (Davis et al. 2001; Peirson et al. 2002).

Positive Effects of Flooding

The positive effects of flood events include the transport of nutrients. The regular input of nutrients maintains the productivity of floodplains and estuaries. These habitats can therefore support a high biomass, commencing at low levels of the food chain, which ultimately translates into larger populations of vertebrate species (Peirson et al. 2002). The increased productivity associated with flooding is regarded to benefit the breeding of many wetland birds (Davis et al. 2001), although specific species may be adversely affected (see below). Flooding also provides variability to flow regimes (Davis et al. 2001; Peirson et al. 2002). Flood events fill freshwater wetlands and form ephemeral (temporary) wetlands. Such recharge events restore water levels in floodplain wetlands, maintaining their quality. As wetlands subsequently dry out, prey species such as fish and eels become concentrated and easier to harvest. This benefits species such as the Black-necked Stork (*Ephippiorhynchus asiaticus*) (Dorfman *et al.* 2001).

New channels and billabongs can be formed during flood events. This creates habitat diversity, which facilitates use of an area by a greater number of species. The creation of billabongs enables new floodplain wetlands to become available as older ones progressively infill. Flood events build, shape and maintain habitats and habitat features (Peirson et al. 2002). Sediment deposited during flood events creates the mudflats required for foraging by migratory waders. As mudflats build they eventually become colonised by mangroves. Mangroves are used as roosting habitats by species such as migratory waders. Floods also transport large logs, which then deposit in wetlands and estuaries. Logs are used as perches by estuarine birds. Floods maintain wetland health by removing organic matter that accumulates during low flow periods, replenishing dissolved oxygen levels (Peirson et al. 2002).

Negative Impacts of Flooding

One of the negative effects of flooding is nest disturbance (Smith 1990). Some threatened birds, such as the Little Tern (*Sterna albifrons*) and the Pied Oystercatcher (*Haematopus longirostris*), nest on beaches and on sand spits in estuaries. Nesting may be disrupted by flood events during the nesting period, which is given in Table 40.

Flood events increase the water levels in estuaries and on floodplains, which may have the effect of temporarily lowering habitat availability (e.g. water may be too deep for foraging). This effect would only last as long as the flood event, but prolonged flooding may result in the mortality and/or redistribution of prey species (e.g. fish, crustaceans) (Peirson et al. 2002). Flood waters trapped behind flood gates not only destroy foraging habitat but can become anoxic and/or can mix with ASS waters. When released these low pH water enter the estuary and can cause fish kills and deplete the food supply for species such as the Little Tern, Osprey (*Pandion haliaetus*) and Black-necked Stork.

Estuarine and Floodplain Fauna

Many fauna species use, but are not dependent on, wetland habitats. These species may still benefit from flooding in general ways, such as nutrient inputs and deposition of logs. For example, logs provide habitat for fish species, which are predated upon by many bird species (e.g. Osprey, Little Tern). However, species dependent on wetland habitat, such as those found in estuaries and on floodplains, are more likely to require management of specific wetland habitats (Table 38).

The fauna described in Table 40 use a variety of habitat types. The life cycle stage most likely to be adversely affected by flooding is breeding. The species that are particularly vulnerable are those that breed on sand spits or beaches, such as the Little Tern and the Pied Oystercatcher. Both species commence nesting in spring, with their young fledging in summer. The protection of potential breeding habitat (e.g. specific sand spits) is a possible management option.

Intertidal mudflats and sandbanks are important foraging habitats. These habitats are used by a wide range of birds, including migratory waders (spring to autumn), the Black-necked Stork and Oystercatchers. The adjacent Mangrove habitat provides roosting habitat for many species. Saltmarshes are secondary foraging habitat for many bird species that forage in intertidal habitats. Floods are likely to alter food availability in intertidal habitats (e.g. freshwater input) in the short-term, but in the longer-term they maintain productivity.

Floodplain swamps are also important foraging habitat for the Black-necked Stork, Magpie Goose (*Anseranas semipalmata*) and the Comb-crested Jacana (*Irediparra gallinacea*) (Table 40). These species also breed in floodplain swamps, although not currently in the study area. Floods would affect nesting attempts by the Comb-crested Jacana, which nests on floating vegetation in the swamp. The Black-necked Stork and Magpie Goose would be less affected because they nest in trees. Floodplain wetlands may also provide temporary foraging habitat for species such as the migratory waders, the Little Tern and Osprey. Floods restore water levels in floodplain wetlands, which is important in maintaining wetland diversity.

The protection of trees adjacent to the estuary, floodplain swamps and the river channels is important in protecting the foraging habitat of the Black Bittern (*Ixobrychus flavicollis*) and the nesting habitat of species including the Black Bittern, Black-necked Stork and Osprey (Table 40).

While the wetland habitats in the study area potentially provide nesting habitat for a number of species, most of these do not currently breed on the Macleay floodplain (Keating and Jarman 2004; Clancy 2005). Management attention is likely to be required to change this situation by improving habitat quality. The most important current function of the wetlands in the study area is to provide foraging habitat for a significant number of threatened and migratory species listed under the TSC Act and the EPBC Act.

Table 40 Seasonal Summary of Key Events in the Life Cycle of Threatened and Migratory Wetland Fauna. Significant fauna are those dependent on estuarine and/or floodplain habitats

Season / Species	Activity	Habitat
Spring		
Magpie Goose [1]	Fledge young, which commence foraging	Swamps
	Foraging	Swamps and floodplains
Black Bittern	Commences nesting	Tree overhanging water; mangroves, Casuarinas (She-oaks)
Osprey	Fledge young, which commence foraging	Open waters: estuary and nearby ocean
Comb-crested Jacana	Commences nesting	Permanent wetlands, nest built of floating vegetation
Pied Oystercatcher	Nesting	Sandy beaches
	Foraging	Beaches, sand bars, mud flats
Migratory waders (incl. threatened species)	Return from northern hemisphere (September onwards)	Mud flats, sand bars, freshwater wetlands
Little Tern [3]	Migrates to S.E. Aust., commences nesting	Sand spits
Summer		
Black Bittern	Nesting	Tree overhanging water
	Roosting	Mangroves
Black-necked Stork [2]	Commences nesting	Large tree near water; estuary or floodplain
Comb-crested Jacana	Fledge young, which commence foraging	Permanent wetlands
	Foraging	Floating vegetation in swamps (e.g. waterlilies)
Pied Oystercatcher	Fledge young, which commence foraging	Beaches, sand bars, mud flats
Migratory waders (including threatened species)	Foraging, need to build energy reserves	Mud flats, sand bars, freshwater wetlands
Little Tern	Fledge young, which commence foraging	Sand spits
	Foraging	Open estuarine waters, flooded coastal wetlands, adjacent ocean
Autumn		
Black Bittern	Fledge young, which commence foraging	Tree overhanging water
	Foraging	Fresh and estuarine wetlands with permanent water
Black-necked Stork	Fledge young, which commence foraging	Productive fresh and saline wetlands
	Foraging	Productive fresh and saline wetlands
Migratory waders (incl. threatened species)	Return to northern hemisphere breeding grounds (March)	
Winter		
Magpie Goose	Commence nesting	Swamps
Osprey	Commence nesting	Large (often dead) tree near water
	Foraging	Open waters: estuary and nearby ocean
Pied Oystercatcher	Commence nesting	Sandy beaches

1 The Magpie Goose is not currently known to nest in the Macleay Valley.

2 The Black-necked Stork is not currently known to nest to the Macleay Valley. However, the study area is near the current southern breeding limit of this species (Clancy 2005).

3 The Little Tern migrates to South East Australia and a small component of the total population breeds there. The Macleay estuary is a former breeding area, but there have been no recent records (Keating and Jarman 2004).

6.2. Aquatic Fauna and their Habitat in the Macleay River Estuary

The Macleay River Estuary has a diverse range of habitats utilised by a suite of aquatic organisms for feeding, reproduction, nursery or shelter. There is limited data on the diversity of aquatic organisms found within the Macleay River Estuary; however some generalised statements relating to the specific importance of each of the habitats can be made based on data from similar estuaries.

Maher et al (2007) found the highest abundance and diversity of benthic macrofauna to be associated with seagrass beds in the Hastings River Estuary and Camden Haven Estuary and this is also likely to be true for the Macleay River Estuary. The increased structural complexity, coupled with high primary productivity rates are the main causal factors for the high abundance and diversity of benthic macrofauna found in seagrass habitats. Intertidal sand shoals are also extremely productive and are commonly associated with high abundances of crustaceans, molluscs and polychaetes which feed on the benthic microalgae, and which in turn are an important food source for commercially and recreationally important fish species. The importance of mangrove and saltmarsh habitats as nursery areas for many important fish and crustacean species is well documented, and this is also likely to be true for these habitats within the Macleay River Estuary.

The structure and function of the estuarine habitats within the Macleay River Estuary needs to be maintained to ensure the continuing health of the aquatic organisms that reside within the estuary. This chapter provides an overview of the significant aquatic fauna of the Macleay River Estuary, and describes some of the key threatening processes.

6.2.1. Status of Threatened Species

Only one threatened aquatic species is likely to currently utilise the Macleay River Estuary. A number of additional threatened species which have been found to occur in the Macleay region either rarely enter estuaries or are thought to no longer occur in the area. A summary of threatened species in or around the area is as follows.

The Green Sawfish (*Pristis zijsron)* is listed as endangered under the Threatened Species Conservation Act 1995 and the Fisheries Management Act 1994. It is also listed as vulnerable under the Environmental Protection and Biodiversity Act 1999. The last sighting of this species in NSW was in 1972, 36 years ago. This species is particularly susceptible to gill and prawn nets due to its studded rostrum (saw), and consequently would be seen in the fish catch statistics (as bycatch) if it was still found in NSW estuaries. It is likely that this species no longer occurs in NSW estuaries.

The Black Cod (*Epinephelus damelii*) is listed as vulnerable under both the Threatened Species Conservation Act 1995 and the Fisheries Management Act 1994 and its reported distribution ranges from the southern coast of Queensland to eastern Victoria. This species does inhabit estuaries on the North Coast of NSW (and this is likely to include the Macleay Estuary). Black Cod inhabit rocky reef areas (Kuiter, 2000) and as such it is likely that their distribution in the

Macleay Estuary would be limited to the rocky areas along the breakwall and the other smaller patches of rocky substrate generally restricted to the lower estuary.

Marine turtles including the Loggerhead (*Caretta caretta*), Green (*Chelonia mydas*) and Leathery (*Dermochelys coriacea*) turtle are known to occur in the Macleay geographical area (DECC 2008). The Loggerhead Turtle is listed as endangered under both the federal Environmental Protection and Biodiversity Act 1999 and the NSW Threatened Species Conservation Act 1995. The Green and Leathery Turtles are listed as vulnerable under both the Environmental Protection and Biodiversity Act 1999 and the Threatened Species Conservation Act 1995. Loggerhead turtles are known to nest on beaches situated on the NSW North Coast which is the southernmost distribution of their nesting range (Limpus *et al*. 1992). Green and Leathery turtles are generally confined to the reefs off the coast and as such do not utilise the Macleay Estuary. These three marine turtle species are oceanodromous, meaning they spend the majority of their life in the ocean and as such are rarely found in estuaries.

Incidental sightings of Dugongs (*Dugong dugon*) are also reported to occur in the Northern Rivers Catchment Management Area, however sightings are extremely rare and are likely to be of individuals that have strayed from their home range (DECC, 2008). The southern limit of viable dugong populations is Moreton Bay on the southern Queensland coast.

There are two shark species protected under the Environment Protection and Biodiversity Conservation Act 1999 that are found in the coastal waters of NSW. They are the Great White Shark (*Carcharodon carcharias*) which is listed as protected under the EPBC Act 1999 as it is migratory and is also listed as vulnerable, and the East Coast population of the Grey Nurse Shark (*Carcharias taurus*) which is listed as critically endangered. These species are oceanadromous (i.e. spend their life in the ocean) and are rarely found in estuaries.

6.2.2. Common Fish Species

Fish species of commercial and recreational importance are listed in Table 41 along with their status, their estuarine residency, spawning season (if known) and the estuarine habitats they utilise. This list is not a comprehensive list of fish species present in the Macleay Estuary, a complete inventory of fish species would require significant field work. However the fish species listed are those targeted by commercial and recreational fishers and as such are subject to the most significant amount of anthropogenic pressure.

Table 41 Fish Species of Commercial and Recreational Importance in the Macleay Estuary

Common Name	*Scientific Name*	Status[1]	Residency	Spawning Season[2]	Estuarine Habitats[3]
Australian Bass	*Macquaria novemaculeata*	C	Spawns in estuary only	Winter	P
Bonito	*Sarda australis*	C	oceanodromous	X	P
Bream, Black and Yellowfin	*Acanthopagrus australis Acanthopagrus bucheri*	C	resident/transient	Winter	P, B, M, S, I
Catfish, Estuary	*Cnidoglanis macrocephala*	C	resident	ND	B
Cobia	*Rachycentron canadum*	C	oceanodromous	X	P
Crab, Blue Swimmer	*Portunus pelagicus*	C	resident typically spawn offshore	Spring-Summer	S, I, B
Crab, Mud	*Scylla serrata*	C	resident typically spawn offshore	Spring-Summer	M, B, I
Dart	*Trachinotus sp.*	C	transient	X	P
Eel, Longfin River	*Anguilla reinhardtii*	C	Catadromous	X	B
Eel, Shortfin River	*Anguilla australis*	C	Catadromous	X	B
Flathead, Dusky	*Platycephalus fuscus*	C	resident/transient	Summer	B, I
Flathead, Sand	*Platycephalus arenarius, Platycephalus bassenis*	C	resident/transient	Summer	B, I
Garfish, River	*Hyporhamphus regularis*	C	resident	Winter/Spring	S, P
Garfish, Sea	*Hyporhamphus australis*	C	resident/transient	Winter/Spring	S, P
Garfish, shortbill	*Hyporhamphus quoyi*	C	resident	Winter/Spring	S, P
Leatherjacket, Unspecified	*family Monacanthidae*	C	oceanodromous	X	S, B
Longtom	*Ablennes hians*	C	resident/transient	ND	S, P
Luderick	*Girella tricuspidata*	C	resident	Winter	S, R, B
Mullet, Fantail	*Paramugil georgii*	C	resident/transient	Winter	S, P
Mullet, Pink-eye	*Trachystoma petardi*	C	resident/transient	Winter	S, P
Mullet, Sand	*Myxus elongatus*	C	resident/transient	Winter	S, P, I
Mullet, Sea	*Mugil cephalus*	C	resident/transient	Winter	S, P
Mulloway	*Argyrosomus japonicus or hololepidotus*	C	resident/transient	Summer	B, P
Octopus	*Octopus australis, Octopus tetricus*	C	resident	ND	B, R
Pilchard	*Sardinops sagax*	C	transient	X	P
Prawn, Greasyback	*Metapenaeus benettae*	C	resident/transient	Summer	B, S
Prawn, School	*Metapenaeus macleayi*	C	resident/transient	Summer-Autumn	B, S
Sandy sprat (whitebait)	*Hyperlophus vittatus*	C	transient		S, P
Shark, Black Tip	*Carcharhinus melanopterus*	C	transient	X	P

[1] C =Common, R = Rare, T = Threatened, E = Endangered

[2] X = species that spawn in open ocean, ND = No data

[3] P = Pelagic Zone, B = Benthic Zone, M = Mangrove Habitat, S = Seagrass Habitat, I = Intertidal Habitat

Common Name	*Scientific Name*	Status[1]	Residency	Spawning Season[2]	Estuarine Habitats[3]
Shark, Fiddler	*Trygonorrhina fasciata*	C	resident/transient	ND	B
Shark, Hammerhead	*Sphyrna sp.*	C	transient	X	P
Shark, School	*Galeorhinus galeus*	C	transient		P, B
Shark, Shovelnose	*Aptychotrema rostrata*	C	resident/transient		B
Silver biddy	*Gerres subfasciatus*	C	resident/transient		S, P
Sweetlip, Unspecified	*Plectorhinchus sp*	C	resident/transient		B, P
Tailor	*Pomatomus saltatrix*	C	transient	X	P
Tarwhine	*Rhabdosargus sarba*	C	resident/transient		P
Trevally, Black	*Caranx lugubris*	C	resident/transient		P
Trevally, Silver	*Pseudocaranx dentex*	C	resident/transient		P
Whiting, Sand	*Sillago ciliata*	C	resident		S, B, I
Yellowtail	*Trachurus novaezelandiae*	C	transient	X	P
Yellowtail kingfish	*Seriola lalandi*	C	transient	X	P

6.2.3. Key Threatening Processes

Estuarine ecosystems are subject to significant anthropogenic influences including eutrophication (due to increased nutrient supply), hydrological stress (through water extraction, water course deviations and drainage of the floodplain), overfishing, acid runoff, water deoxygenation (associated with flood events), habitat destruction/modification (including riparian vegetation) and gross pollutant inputs (eg plastic bags, rubbish etc). These impacts can have chronic or acute impacts upon the ecosystem depending upon the timing and magnitude of the events.

The Macleay Estuary is subjected to all of the mentioned threatening processes to some degree although there is insufficient data to determine the magnitude of these threatening processes on specific species.

Eutrophication

Eutrophication can be defined as the increase in the supply of organic matter to an estuary (Nixon, 1995), and typically is related to an increased supply of nutrients which stimulates phytoplankton and macroalgae growth. When this “excess” organic matter dies and decomposes it consumes oxygen which can lead to anoxic conditions at the benthic surface, causing stress and even mortality to benthic organisms. Coupled with this anoxia is the release of nutrients back to the water column, which can stimulate more plant growth which continues the cycle.

Within the Macleay Estuary there are signs of eutrophication in the Upper Estuary around Kempsey with dense beds of aquatic macrophytes becoming well established. These beds however act as a net sink for nutrients and most likely act as an efficient filter, efficiently stripping the water column of nutrients preventing algal blooms, as discussed in Section 5.1.2. The macrophyte beds most likely act as an important habitat area both structurally and in terms of supply of organic matter to higher trophic levels (including fish). There is no data on the functional importance of these beds, and further investigation is required.

In the mid and lower estuary phytoplankton blooms occur adjacent to the Gladstone wastewater discharge, Grassy Head and Stuarts Point, (discussed in Section 5.1.2). These blooms are associated with nutrient inputs and are an indication of some degree of eutrophication in these areas. If these blooms increase in magnitude and frequency, shifts in the trophic structure and the aquatic organism community composition will occur. Planktivorous fish will start to dominate the icthyfauna, the benthic community will become dominanted by species tolerant of low dissolved oxygen, and aquatic organism diversity will decrease. This can have flow on financial effects for the communities situated along the Macleay Estuary. A decrease in fisheries production has an economic impact on commercial fishers and is likely to reduce recreational fishing which may in turn also impact on tourism. This should be a key area of focus in sustaining the health of the estuary, and should be incorporated into future monitoring programs.

Hydrological Stress

Hydrological stress within the Macleay Estuary is primarily associated with the historical drainage of floodplain wetlands, and current water extraction from the upper catchments. The *Stressed Rivers Assessment Report* (DLWC, 1999) found that 18% of the subcatchments (based on 33 subcatchments) of the Macleay River suffered from medium to high water extraction stress at the 1999 water extraction levels. Based on full development of water licences this percentage would increase to over 24%. Water extraction reduces the inflow of freshwater to an estuary and shifts the saline/freshwater interface landward. This has implications for freshwater aquatic life as habitat area shrinks as the saltwedge intrudes further upstream (see Bishop, 2006).

Many estuarine organisms use changes in flow as a trigger mechanism for critical life-history events such as spawning (Harris, 1986), migration and recruitment (Strydom et al. 2002). Small freshes also deliver nutrients to the estuary which may be an important element in sustaining primary production (Alber, 2002). The salinity gradient profiles undertaken throughout 2006/2007 displayed saltwater intrusion beyond Kempsey during low rainfall periods suggesting some degree of hydrological stress during these periods.

Overfishing

As with most NSW estuaries, the Macleay Estuary is subject to considerable fishing pressure. Both recreational and commercial fishers harvest fish from the Macleay Estuary, with the main species caught by commercial fishers being mullet, luderick, eels and mud crabs (Table 42). With the exception of eels these species are also important to recreational fishers.

Table 42 Value of Commercial and Recreational Fishing for 1998/1999

Species	Weight (kg)	% of Weight	Value (Dollars)	% of Dollars	Recreational Fishery Value
Bonito	10	0.0%	$39	0.0%	Low
Bream, Black and Yellowfin	2,023	2.2%	$15,616	5.5%	High
Catfish, Estuary	4	0.0%	$5	0.0%	Low
Catfish, Unspecified	2	0.0%	$6	0.0%	Low
Crab, Blue Swimmer	74	0.1%	$462	0.2%	High
Crab, Mud	8,696	9.5%	$115,000	40.7%	High
Dart	16	0.0%	$46	0.0%	Medium
Diamond Fish	65	0.1%	$237	0.1%	Low
Eel, Conger	3	0.0%	$9	0.0%	Low
Eel, Longfin River	9,239	10.1%	$14,869	5.3%	Low
Eel, Shortfin River	2,029	2.2%			Low
Eel, Unspecified	99	0.1%	$384	0.1%	Low
Fish, Unspecified Estuary	195	0.2%	$566	0.2%	
Flathead, Dusky	1,193	1.3%	$3,965	1.4%	High
Flathead, Sand	11	0.0%	$25	0.0%	High
Garfish, River	135	0.1%	$357	0.1%	Medium
Garfish, Sea	1	0.0%	$5	0.0%	Medium
Garfish, shortbill	63	0.1%	$297	0.1%	Medium
Leatherjacket, Unspecified	4	0.0%	$10	0.0%	Medium
Longtom	8	0.0%	$19	0.0%	Low
Luderick	12,401	13.6%	$14,647	5.2%	High
Mullet, Fantail	416	0.5%	$381	0.1%	Medium
Mullet, Pink-eye	2,746	3.0%	$2,999	1.1%	Medium
Mullet, Sand	1,075	1.2%	$1,042	0.4%	Medium
Mullet, Sea	43,841	47.9%	$64,853	23.0%	Medium
Mullet, Unspecified	58	0.1%	$90	0.0%	
Mulloway	2,052	2.2%	$14,183	5.0%	High
Nipper	127	0.1%			High
Octopus	11	0.0%	$45	0.0%	Low
Old Maid	12	0.0%	$19	0.0%	Low
Pike	7	0.0%	$10	0.0%	Medium
Pilchard	243	0.3%	$400	0.1%	Low
Pipi	25	0.0%	$53	0.0%	High
Prawn, Greasyback	481	0.5%	$3,420	1.2%	Low
Prawn, School	1,842	2.0%	$14,888	5.3%	Low/Medium
Sandy sprat (whitebait)	4	0.0%			Low
Shark, Black Tip	486	0.5%	$2,291	0.8%	Low
Shark, School	146	0.2%	$666	0.2%	Low
Shark, Unspecified	66	0.1%	$195	0.1%	
Silver biddy	7	0.0%	$17	0.0%	High
Sweetlip, Unspecified	8	0.0%	$42	0.0%	High
Tailor	42	0.0%	$190	0.1%	High
Tarwhine	3	0.0%	$14	0.0%	High
Trevally, Silver	521	0.6%	$1,533	0.5%	High
Whiting, Sand	1,009	1.1%	$8,478	3.0%	High
Totals	**91,498**		**$282,371**		

Whilst there is minimal data on the recreational catch of fish in the Macleay Estuary, commercial fish catch is readily available from NSW DPI. By comparing the total fish catch of the Macleay Estuary to the fish catch in similar estuaries throughout NSW (i.e. mature barrier estuaries, Type IIID as defined by Roy et al. 2001) an indication of the commercial fishing pressure within the Macleay Estuary can be interpreted. Diagram 18 and Diagram 19 display commercial fish catch for the Macleay Estuary compared to other geomorphically similar estuaries throughout NSW. Data is based on total fish landings (kg) normalised for estuary area.

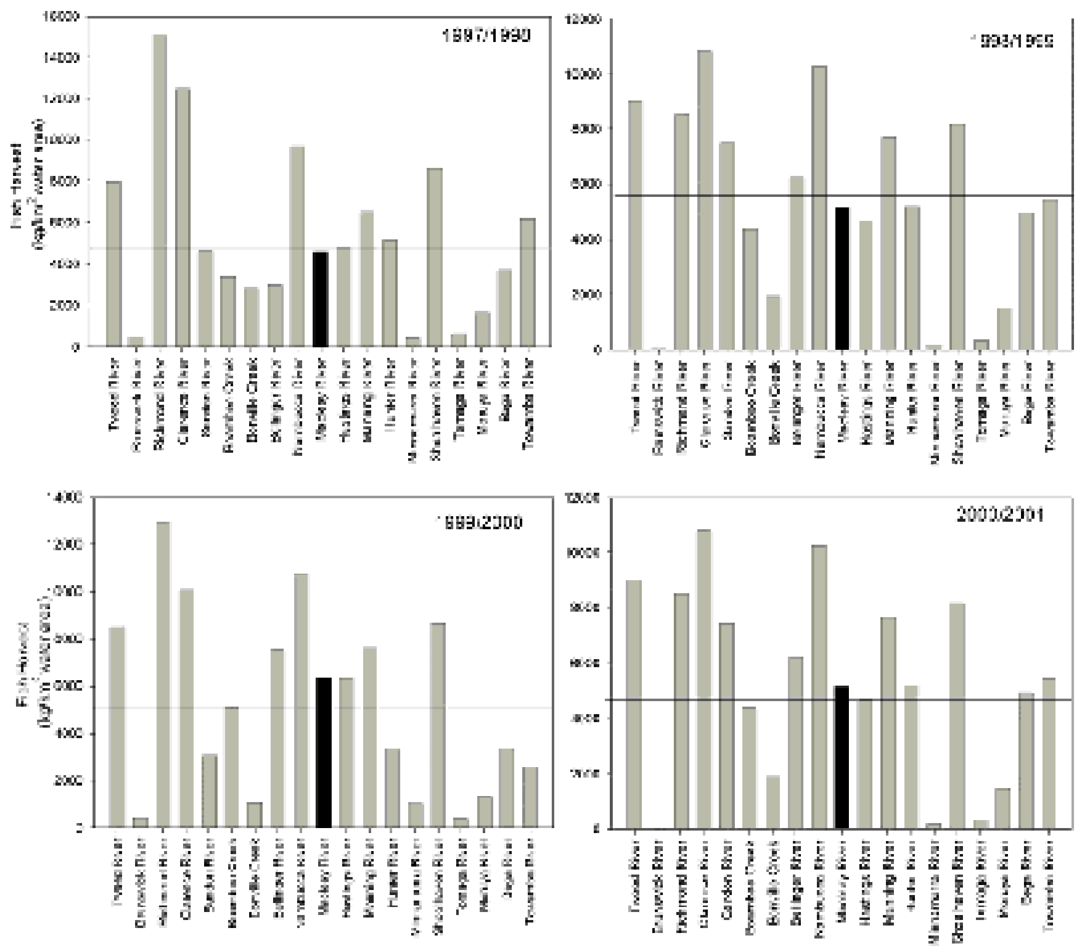

Diagram 18. Comparison of commercial fish catch in the Macleay Estuary (dark bar) to other similar estuaries in NSW for the financial years 1997/98 to 2000/01 (data normalised for estuary area). Line represents mean value for all estuaries.

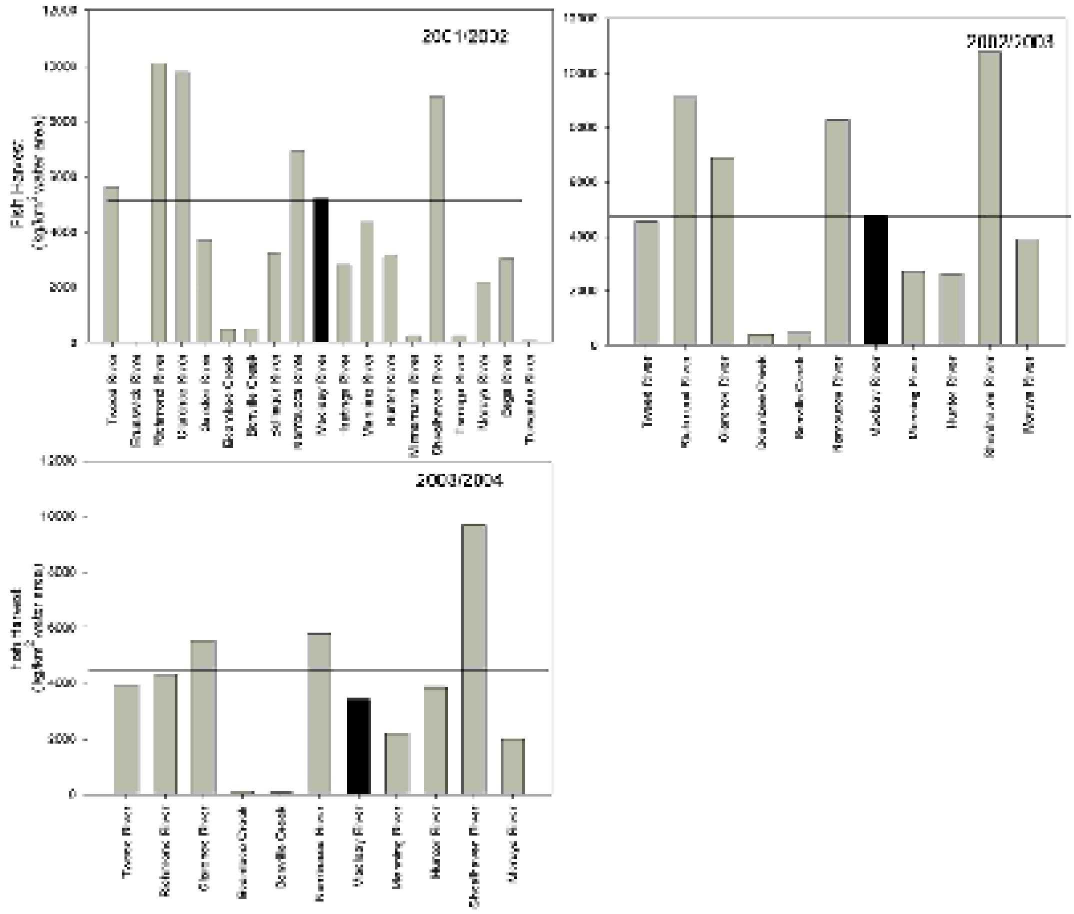

Diagram 19. Comparison of commercial fish catch in the Macleay Estuary (dark bar) to other similar estuaries in NSW for the financial years 2001/02 to 2003/04 (data normalised for estuary area). Line represents mean value for all estuaries.

Diagram 18 and Diagram 19 show that the commercial fish catch within the Macleay Estuary has remained relatively stable around ~ 4000 kg/km ^{2}/year and is generally similar to the average fish catch for NSW Type IIID estuaries. This suggests that stocks of commercial fish are above the threshold for maintaining adequate recruitment to sustain the population. This data also suggests that recreational fishing pressure on those same species is not excessive as a decline in the commercial fish catch would be evident if this was the case.

Overall the data available suggests that generally the stocks of fish targeted by commercial fishers (which incorporates most species targeted by recreational fishers) are stable and that overfishing does not appear to be occurring. However data on by-catch is not as readily available and it is possible that stocks of some non-target species may in fact be in decline. More data is required for a complete assessment of the fish stocks within the Macleay in particular, those species that are not recorded in commercial catch returns that may be of integral importance to the estuarine ecosystem.

More detail on commercial and recreational fishing is contained in the following chapter on Waterway Usage.

Acid Runoff/Water Deoxygenation Events

As discussed in Section 5.6, acid sulfate soils are formed in estuaries and oceans by the deposition of marine derived reduced sulphur minerals (mainly pyrite and iron monosulphides). During the Holocene period ~ 10 000 years ago, sea levels were approximately 35 m higher than present day and as a result coastal floodplains along the NSW coast (including the Macleay) were inundated. Under the right conditions (typically high organic carbon loads, high dissolved iron concentrations and reducing conditions) acid sulfate soils were formed. Sea level has regressed and these soils are now found within the floodplains of most NSW estuaries.

Whilst these soils remain permanently inundated such as in wetlands and areas of high groundwater levels, they remain in a reduced state and have a minimal impact on the surrounding environment. These are often referred to as potential acid sulfate soils. However, exposure of the soils causes oxidation to sulfuric acid. The exposure of acid sulfate soils in the Macleay floodplain has been exacerbated by the drainage of backswamp areas, and construction of an extensive flood mitigation system which is comprised of 138 km of drains, 180 flood control structures and 352 floodgates (Henderson 2001). Runoff and floodwaters subsequently passing over the acidified soils can transport and distribute them throughout the floodplain and into waterways. Acidified floodwaters can also cause the release of bound metals which become soluble under lower pH conditions some of which are toxic to aquatic organisms (eg aluminium). When the water drains from the floodplain to the estuary, or floodgates are opened, this acidic, metal rich, low dissolved oxygen (DO) water can have a significant impact upon aquatic organisms, leading to mass mortality in some extreme cases. The effects of acid runoff are normally coupled with the stripping of dissolved oxygen from the water column due to the break down of organic matter on the floodplain and organic matter washed into the estuary from large rainfall events (see Eyre et al, 2006 for example in the Richmond River).

Fish kills have occurred periodically in the Macleay Estuary following flood events. Fish mortality has been linked to a lack of DO in the water column (e.g. Kemsley, 2001). This is likely to be due to a combination of the breakdown of organic matter on the floodplain and in the water column, and the chemical oxygen demand associated with the oxidation of acid sulfate soils. Inherent difficulties exist in trying to prevent the deoxygenation of water due to the break down of organic matter on the floodplain due to the number of stakeholders, and the large-scale nature of the issue. Simple measures such as the restoration of riparian vegetation communities may assist in reducing the rate at which deoxygenated water re-enters the estuary. Management of floodgates and acid sulfate soil areas should focus on minimising the disturbance of acid sulfate soils (and hence preventing oxidation of pyrites) and leaving floodgates open wherever possible (Pollard and Hannan, 1994).

Habitat Destruction/Modification

Estuarine habitats have been mapped and are shown in Figure 43. The importance of seagrass habitats to estuarine functioning is well documented (e.g. Pease, 1981: Bell and Pollard, 1989 Pease, 1999; Saintilan, 2004). Seagrass provides structural habitat and is a key area for carbon fixation (food supply) within many subtropical estuaries. Within the Macleay Estuary seagrass is generally restricted to the Macleay Arm which has extensive meadows of *Zostera capricorni*. These seagrass beds are important nursery habitat areas for many commercially important fisheries species, and due to the restricted distribution of seagrass within the Macleay Estuary it is essential to maintain optimal water quality conditions in the Macleay Arm for seagrass survival. The key water quality parameters for seagrass health are minimal turbidity/suspended solids (to ensure sufficient light penetration) and minimal inorganic nutrient inputs (to prevent algal dominance).

Mangrove and saltmarsh areas are also critical habitats to estuarine ecosystems as they provide nursery habitat and nutrient cycling, and supplement food supply to the estuarine food chain. Mangrove and saltmarsh habitats are restricted to the lower estuary, in areas where clearing for agriculture has not been feasible. Mangroves, saltmarshes and seagrasses are protected under the Fisheries Management Act 1994, preventing future destruction. These habitats can be significantly affected by changes in hydrology. Increased flow can cause erosional stress and dieback in even well established mangrove stands (Jiminez et al, 1985), as can significant deposition of fine particulate materials during flood inundation (Ellison 1998). Management of the lower estuary needs to ensure minimal changes in hydrology to maintain the health of the saltmarsh and mangrove habitats.

Exotic species

Without extensive surveys of the aquatic flora and fauna (including zooplankton and phytoplankton) within the Macleay Estuary it is difficult to ascertain the impact of exotic species. One notable and obvious exception is the dense macrophyte beds in the upper estuary (shown in Figure 43), which have overtaken the native aquatic flora in this area. It is likely that these beds are composed predominantly of dense waterweed (*Egeria densa*) and Elodea (*Elodia canadensis*). These are likely to have altered the way in which the upper estuary functions, in particular the habitat structure and productivity. There may also be feedback mechanisms associated with dietary shifts from the native primary producers to the introduced Elodea. These beds however seem to be effectively removing excess nutrients from the water column, which otherwise would be available to promote nuisance algal blooms. More study into the importance of these beds in terms of habitat structure and biogeochemical cycling is recommended.

6.2.4. Health of Aquatic Ecology in the Macleay Estuary

Without extensive data on species diversity and abundance it is very difficult to give a definitive overview of the health of the aquatic ecology within the Macleay Estuary. Based on the commercial fish catch data it appears that fish stocks are in good condition, as the catches have remained relatively stable over the last decade. Reports on the recovery of the Macleay Estuary following the large fish kill in 2001 indicate that the estuarine fish stocks showed considerable recovery within 5 months (Kennelly and McVea, 2002). This suggests that the aquatic ecology is quite robust within the Macleay Estuary and recruitment from other nearby estuaries and coastal waters supplements in situ recruitment.

The most critical habitats for maintaining estuarine ecological health occur within the Macleay Arm, where most of the seagrass meadows, mangrove stands, and saltmarsh are situated. These habitats are essential nursery areas for many aquatic organisms (including important commercial and recreational fish species) and consequently management should focus on maintaining optimal conditions for sustaining these habitats. Minimising changes in hydrology, turbidity and nutrient concentrations will ensure the protection of these habitats, as described in the preceding water quality chapter (Chapter 5).

Studies in the nearby Hastings River and Camden Haven Estuaries (Maher et al 2007) have found that intertidal and shallow subtidal shoals are the significant areas of estuarine primary productivity and this is likely to be the case in the Macleay Estuary as well. As with seagrass meadows, to maintain the productivity in these habitat areas it is crucial to minimise turbidity and the nutrients available to phytoplankton and macroalgae. Primary productivity (by terrestrial plants, mangroves, algae and seagrasses) is the base of the food web, without which higher order aquatic organisms can not survive. The nutrient budget discussion in Section 5.3 and the summary and synthesis of key biogeochemical processes in Section 5.7, emphasise the importance of carbon production in the intertidal shoals and seagrass areas, with estuary wide production being dominated by benthic microalgae. Management should focus on maintaining the balance of primary producers and the productivity rates within the Macleay Estuary. This will ensure that the trophic structure and hence the abundance and diversity of aquatic organisms within the Macleay River Estuary are maintained.

7. WATERWAY USAGE

The Macleay estuary and surrounding areas offer a wide variety of activities, including water sports, commercial and recreational fishing, bushwalking, and cultural activities. The natural environment is highly productive, and supports a number of commercial uses including fishing, oyster farming, agriculture and tourism. However, these uses along with increasing urban development have had significant impacts on the environment and areas of cultural significance. It is therefore of increasing importance that a balance is met between environmental management, cultural heritage and human activities. Both the Kempsey Shire Council 20 year *Community Strategic Plan* and the *Macleay Valley Coast Tourism Strategic Plan 2005-2009* (ATS Group, 2005) emphasize the need for greater promotion and protection of the area's environmental and social values and assets.

The following sections provide a summary of the main waterway uses within the Macleay Estuary, whilst 18
Figure 7 (page 20) shows the locations of the current estuary access and usage.

7.1. User Groups and Stakeholders

The number of user groups reflects the wide range of activities which occur within the Macleay estuary. These are summarised below:

- Local residents in urban centres and towns,
- Developers,
- Aquaculture industry,
- Commercial and recreational fishers,
- Agriculture industry,
- Indigenous groups,
- Environmentalist groups, and
- Tourists and the tourism industry.

These groups rely on the Macleay estuary for resources, whilst also impacting on each other and the environment. It is therefore necessary that a balance is met between the needs of each group and how these needs impact upon the surrounding estuary.

7.2. Fishing and Aquaculture

The Macleay estuary offers a full range of fishing opportunities, both within the river and along the coastline. Warm currents and the proximity to the continental shelf provide ideal conditions for a number of different species (Kempsey Council website, 2008). Species such as freshwater bass and catfish can be found in the upper reaches, with estuarine species such as bream, flathead and luderick can be found near the entrance. The area offers significant opportunities for both commercial and recreational fishing as well as aquaculture.

7.2.1. Aquaculture

The oyster industry is the only aquaculture industry which currently operates within the Macleay estuary. In 2000, the North Coast Sustainable Aquaculture Strategy (NSW DPI, 2000) identified 1890 ha of land within the Macleay estuary which would be suitable for land based aquaculture, however, this is not currently developed for such purpose.

Oyster farming is currently the most valuable fishery in NSW, valued at $34.6 million for the year 2006/2007. It has consequently been the focus of a state wide strategy to manage the industry at a sustainable level under the *NSW Oyster Industry Sustainable Aquaculture Strategy* (OISAS) (NSW DPI, 2006[1]). OISAS is given effect through the State Environmental Planning Policy (SEPP) 62 – Sustainable Aquaculture. This policy requires that all development which has the potential to have an adverse impact on oyster production is referred to the NSW Department of Primary Industries (DPI) for comment. In determining a development application, the consent authority must take any NSW DPI comments into consideration.

OISAS involved identifying areas that were considered to be suitable as Priority Oyster Aquaculture Areas (POAA) for oyster farming and establishing water quality and flow objectives to improve the viability of the industry. POAAs are areas where commercial oyster aquaculture is a priority intended outcome. The water quality objectives outlined in OISAS are shown below in Table 43.

Table 43 OISAS Water Quality Objectives (source: NSW DPI, 2006 [1])

Parameter	Guideline	Source
Faecal (thermotolerant) coliforms	90th percentile of randomly collected Faecal coliform samples do not exceed 43MPN or 21 MF/100mL	ASQAP Operations Manual 2002 and the NSW Shellfish Program Operations Manual 2001.
pH	6.75 – 8.75	Schumway (1996).
Salinity	20.0 – 35.0 g/L	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000).
Suspended solids	<75 mg/l	
Aluminium	<10μg/L	
Iron	<10μg/L	
Other parameters	For other parameters please refer to Section 4.4 and Section 9.4 of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000)	

The oyster industry is reliant on good water quality to grow healthy oysters which are fit for human consumption. Oyster aquaculture in NSW is threatened by declining estuarine water quality, increased use of waterways and development adjacent to estuaries. These affect both oyster productivity and the suitability of oysters for human consumption (NSW DPI, pers. com., 2008). As oysters feed by filtering water and extracting nutrients and other suspended material, they also play an important role in maintaining adequate water quality and are seen as indicators of estuary health (NSW DPI, 2006 [1]; NSW DPI, pers. com., 2008).

The Sydney rock oyster (*Saccostrea glomerata*) is the primary species which is harvested both within the estuary and throughout the state. The Macleay Oyster Industry produces on average approximately 2% of the total NSW production, valued at approximately $530,000 (NSW DPI, 2001 to 2008[1]). Diagram 20 shows the quantity and value of the Macleay Oyster industry from 1999/2000 to 2006/2007.

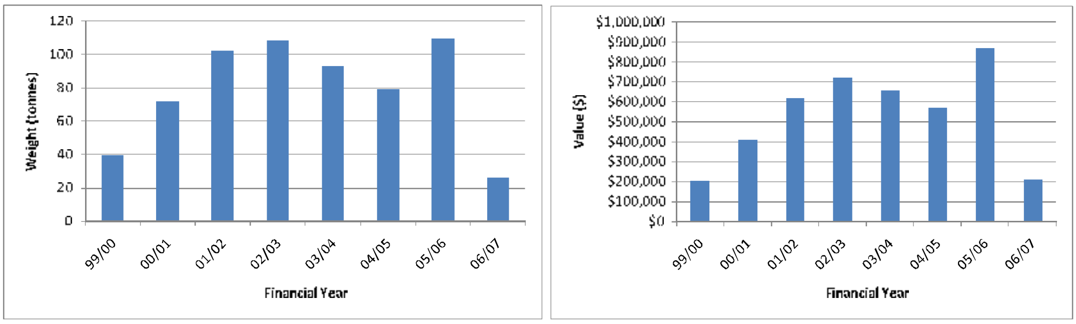

Diagram 20. The Macleay Estuary oyster industry showing (a) total production and (b) total value for the years 1999/2000 to 2006/2007 (source: derived from NSW DPI 2001 to 2008 [1]).

The Macleay oyster leases are currently contained within three harvest areas, all of which are close to the estuary mouth, as shown in Figure 45. These harvest areas are Clybucca Creek, Fishermans Reach and New Entrance (NSW Food Authority, 2008 [1]). All current leases and some former leases were identified as POAAs in OISAS, as shown in Figure 46. The operation of each area is regulated by a separate harvest area management plan. Clybucca Creek and Fishermans Reach harvest areas are classed as conditionally restricted, which requires oysters to be depurated before consumption. Water quality data suggests that faecal coliform concentrations are slightly higher in these areas (NSW Food Authority, 2005). New Entrance is conditionally approved, which means that oysters can be harvested directly except for under predicted adverse conditions such as rainfall exceeding a trigger level. The water quality objectives in OISAS aim to improve all oyster harvest areas to direct harvest standard, enabling oysters to be sold directly for human consumption.

A number of depuration plants are located in oyster sheds adjacent to the entrance to Spencers Creek. These draw estuarine water from the area. Depuration is a purification process where oysters are held in land based plants containing purified estuarine water for a minimum period of 36 hours. This allows the purging of their gastrointestinal contents, including any potentially harmful bacteria. The estuarine water used in the depuration plant is exposed to high intensity, germicidal ultra-violet light twice every hour to ensure its quality (NSW DPI, pers.com., 2008; SafeFood NSW, 2001).

The Department of Environment and Climate Change (DECC) has established the *NSW Water Quality and River Flow Objectives* for each catchment area including the Macleay (DECC website, accessed 2008). As part of the consultation process for Macleay, oyster growers

FIGURE 45
NSW FOOD AUTHORITY
OYSTER HARVEST AREAS

SOURCE: NSW FOOD AUTHORITY, 2008

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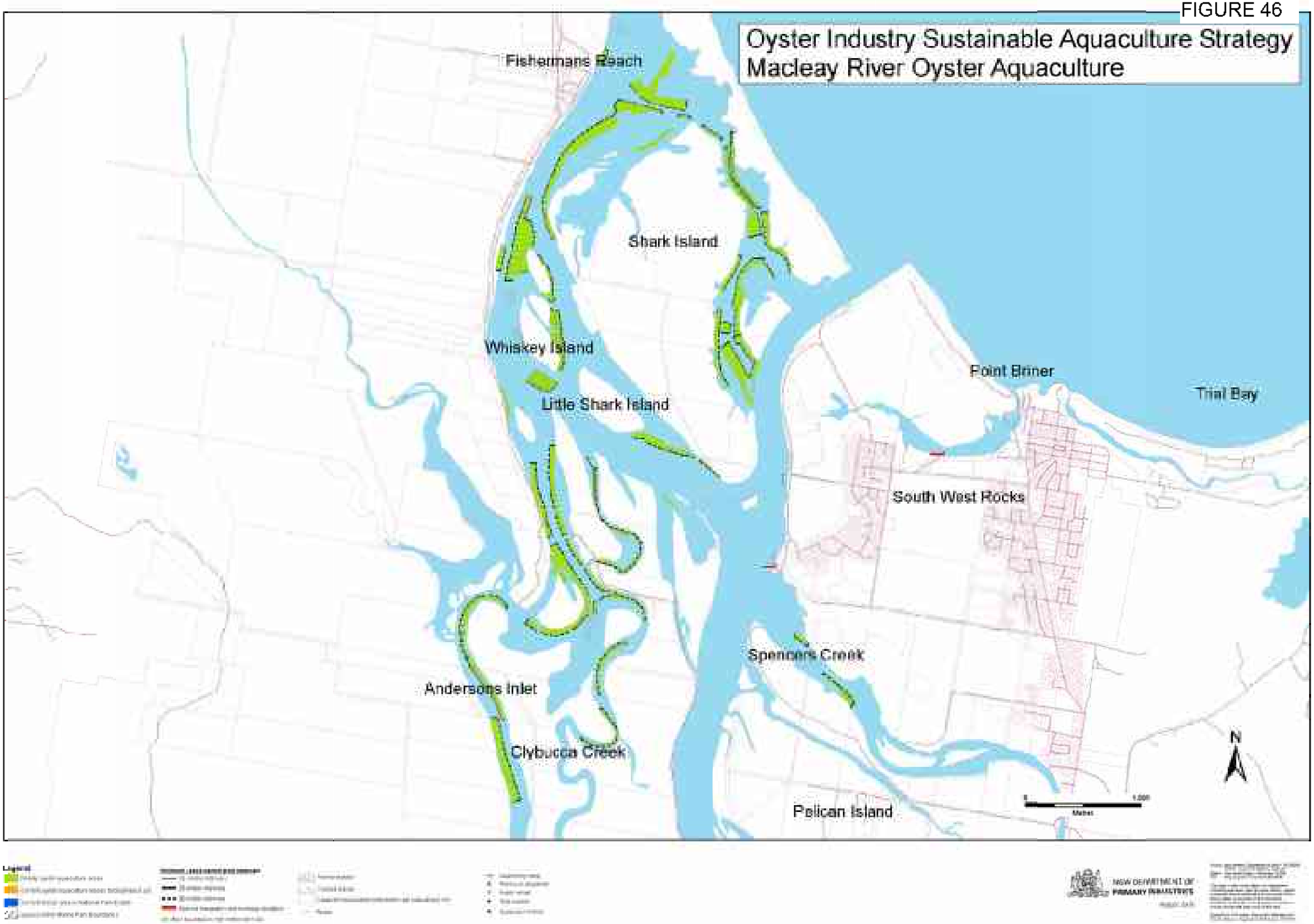
FIGURE 46



J://Jobs/Admin/ReportFigures/Other/Figure46_OysterStrategy.pdf expressed concern over discharges such as inadequately treated sewage, which have the potential to impact upon the water quality in the estuary. Whilst pathogens originating from faecal matter (both human and animal) generally present the highest risk of contamination, food poisoning from oyster consumption is extremely rare (NSW DPI, pers. com., 2008). There have been no recorded food poison outbreaks in the Macleay due to the oyster industry.

During the period March 2000 to March 2008, approximately 20 routine closures occurred. The New Entrance harvest area had the most with 24 closures, followed by Clybucca Creek (20) and Fishermans Reach (17). The higher number of closures at New Entrance were primarily due to the stricter conditions stipulated by the harvest area management plan compared with the other two areas. The majority of closures for all areas were due to rainfall events. Water quality can be reduced by runoff from the surrounding catchment carrying contaminants into the estuary. Both rainfall and water quality data are therefore collected to determine whether closures are necessary. Low salinity levels can also trigger a closure, as they are often an indication of significant rainfall in upstream areas (NSW Food Authority, 2008 [2]; NSW Food Authority, pers. com., 2008). Minimum salinity levels must be maintained for oyster health (Dove, 2003). The remaining closures were primarily due to microbiological levels exceeding trigger values (NSW Food Authority, 2008 [2]).

Water quality sampling undertaken as part of this study over the period September 2006 to August 2007 included measurement of salinity as well as pH and total suspended solids. Over this period, salinity did not drop below the lower OISAS limit of 20mg/L in the Macleay Arm. The sample locations in other parts of the lower estuary could not be directly compared with the location of the oyster leases, as they were based on salinity rather than geographic locations. In terms of pH, no samples exceeded the OISAS guidelines during the sample period, although during August 2007 they were close to 6.75 in the Macleay Arm. Total suspended solids only exceeded 75mg/L once during November 2006. This may be related to there being increased flow during that month, which is likely to increase sediment transport.

The impact of rainfall on water quality is also reflected in data collected as part of the *Water Bacteriology and Phytoplankton Survey* (NSW Food Authority, 2005). The survey measured faecal coliforms and potentially toxic phytoplankton species present between January 2003 and July 2005 at a number of sites within commercial shellfish harvest areas in NSW, including the Macleay estuary. Faecal coliform levels were found to be elevated within the Macleay estuary after rainfall events.

Water quality is routinely measured at a number of different pollution sources throughout the catchment. These include sewage treatment plant discharge sites, septic tank discharge areas and cattle access locations. Generally, water quality is only observed to deteriorate during rainfall events, although there are some instances of reduced water quality at other occasions. This is reported to occur most frequently in the Fishermans Reach area (NSW Food Authority, pers. com., 2008).

Compared with other NSW estuaries, the Macleay estuary appears to have relatively good water quality in the New Entrance area. New Entrance is one of only 3 approved harvest areas in the NSW North Coast, whilst Clybucca and Fishermans Reach are two of 21 restricted areas (NSW Food Authority, pers.com., 2008). The NSW Food Authority 2003-2005 survey found that the highest mean faecal levels occurred within Clybucca Creek, whilst the highest faecal coliform counts during the sample period occurred in Fishermans Reach and Spencers Creek after rainfall. Only one sample taken near Kemps Corner exceeded the trigger value for potentially toxic phytoplankton species.

The Macleay oyster industry has also been affected by the oyster disease QX since 2006, a disease caused by the protozoan *Marteilia sydneyi*. Whilst QX has not been found to transfer to humans, it has had a significant impact on the oyster industry. QX is thought to only affect the Sydney rock oyster and has been found throughout the majority of estuaries along the southeast Queensland and northern NSW coast (NSW DPI website QX Oyster Disease, accessed 2008; NSW Food Authority, pers. com., 2008).

QX initially resulted in a death rate of approximately 70% of oysters in the Macleay in 2006, which has improved to approximately 30%. This improvement has not been seen in the majority of other affected locations. Whilst the cause of QX is not currently known, it is thought to be linked to poor water quality, which can compromise the immune system of oysters. However, areas in Macleay (such as Clybucca Creek) which have low pH levels due to acid sulfate soil runoff, have been found to have lower incidences of QX deaths. It is thought that the acidic water kills the QX disease (NSW Food Authority, pers. com., 2008).

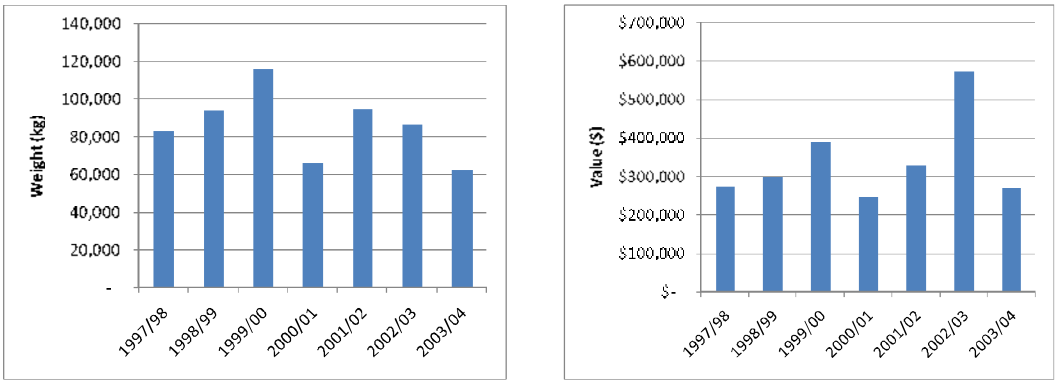
Ashley and Graham (2001) investigated the bioaccumulation of heavy metals in oysters as part of a wider study of heavy metal loadings in the Macleay. Of the four samples taken, some bioaccumulation of copper, zinc and arsenic was found, although levels were less than or close to the Australian and New Zealand Food Authority (2000) permitted concentrations. It was also found that concentrations in wild oysters were higher than the single commercial oyster sample. No bioaccumulation of lead, selenium and antimony was observed. Heavy metal contamination testing for cadmium, copper, lead, mercury, selenium, zinc and arsenic, is also undertaken by the oyster industry every three years. Previous results (1999, 2002 and 2005) indicated levels have been below trigger values (NSW Food Authority, pers.com., 2008).

7.2.2. Commercial Fishing

The Macleay River is part of the Region 3 – North Coast fishing region, which extends from Wooli Wooli River in the north to Camden Haven River in the south (NSW DPI, 2008 [2]). Commercial fishing within the Macleay estuary is part of the Estuary General Fishery, which is one of 9 fisheries within NSW. The commercial fleet also accesses a number of oceanic fisheries. An Environmental Impact Statement (EIS) and Fishery Management Strategy have been developed for each fishery, to assess the impacts of the fishing industry and define specific management rules.

Commercial fishing in the Macleay estuary and surrounds is a locally significant industry, generating on average 86,000 kg of fish, which is worth approximately $340,000 per annum (based on 7 years of data from the 1997/98 season onwards). This constitutes on average approximately 1.7-1.8% of the total NSW estuary catch per year (NSW DPI, 2004 [1]). For the 1997/98 and 1998/99 seasons, the Macleay was listed within the top 20 estuaries in NSW based on the total weight of fish sold (NSW Fisheries, 2001). Over 50 different species are caught within the estuary or close to the estuary mouth. Sea mullet accounts for the most significant species by total weight (approximately 45%), whilst mud crabs are the most significant species caught in terms of total value (approximately 38%), based on 1997/98 and 1998/99 catch data (NSW DPI, 2004[1]). Other predominant species include luderick, eels, black and yellowfin bream, sand whiting, mulloway and school prawns. The majority of species utilise both the estuary and the ocean, generally within inshore areas.

Fishing effort throughout the year is generally consistent, although there is some increased activity during particular seasons such as the mullet run over autumn (NSW DPI, pers. com., 2008). Despite some yearly variations in catch size and catch value, the industry has remained relatively stable between 1997/98 and 2003/04, as shown in Diagram 21.



(a) (b)

Diagram 21. Variation in Macleay Estuary commercial catch between 1997/98 and 2003/04 showing (a) total gross catch weight and (b) total catch value.

The primary fishing methods used are mesh and haul netting, crab and fish trapping, hand lining and hand gathering from ocean beaches. A number of netting restrictions are in force throughout the Macleay, its tributaries and South West Rocks Creek, as specified under a Section 8 Notification of the *Fisheries Management Act 1994* (NSW DPI website – Fishing Closure, accessed 2008).

Historically, the commercial fleet was distributed between Jerseyville, New Entrance at South West Rocks and at South West Rocks Creek. However, between 1978 and 1991, the number of vessels at South West Rocks Creek reduced from 17 to 6, primarily due to the entrance bar across the creek and sedimentation within the creek (GHD, 1992). The fleet currently consists of 14 vessels operating out of Jerseyville (NSW Maritime, pers.com., 2008). The majority of commercial fishing is offshore, with major activities including prawn trawling, fish and lobster trapping, hand lining and haul netting from ocean beaches. Offshore fishing is part of four different fisheries: Ocean Trap and Line, Ocean Trawl, Ocean Haul and Lobster Fisheries. The average ocean catch between 1997/98 and 2003/04 was approximately 152,000 kg, worth approximately $1 million (NSW DPI, 2004 [1]). The majority of the combined estuary and ocean catch is sold to external markets, with a proportion also sold locally through the Fisherman's Co-operative at Jerseyville.

The fishing industry is vulnerable to poor water quality within the Macleay and its tributaries. Poor water quality can arise after a flood event, due to the mobilisation of pollutants and the deoxygenation of floodwaters caused by the decay of vegetation on the surrounding floodplains. The most recent occurrence of significantly reduced water quality was following a flood in March 2001, which resulted in a major fish kill and 3.5 months of closures. The fish kill was most severe downstream of Jerseyville, and affected a number of commercially significant species such as luderick, yellowfin bream, dusky flathead and sand whiting (Macbeth et al., 2002). As discussed in Chapter 3 and as indicated by NSW Fisheries water quality testing, the primary cause of the fish kill was likely to be the release of deoxygenated water within the Macleay River (Macbeth et. al., 2002). The closures were partially lifted in July 2001, although some closures remained in place until March 2002. These closures are likely to account for the reduced catch during the 2000/01 season shown in Diagram 21.

7.2.3. Recreational Fishing

Recreational fishing is a popular activity in the Macleay River Estuary. Activity is highest during holiday periods, particularly over the Christmas/New Year period. There are a number of fishing clubs (including two based from South West Rocks, two from Kempsey, one at Smithtown and one at West Kempsey).

Recreational fishing occurs in all areas of the Macleay River, from its upper reaches to the ocean entrance and includes crabbing, prawning and hand-line fishing. In 2001, a survey of recreational fishing in the lower Macleay was conducted over four months (July to October) for NSW Fisheries (Steffe and Macbeth, 2002). The survey covered the area from south of Kinchela to the entrance. It was found that approximately 48% of recreational fishers were locals and approximately 40% of total fishing was boat based with 60% shore based. The most popular fishing area was near the Entrance (38% of total hours), followed by the Kemps Corner/Clybucca area (28%), Stuarts Point (21%) and the main river (13%). During the period sampled, the fishers surveyed reported approximately 36% of boat based trips to be unsuccessful and 61% of shore based trips.

Over the four month period, approximately 45,300 fish and crabs were caught (25.2 tonnes), across 16 different taxa. The primary species caught were luderick, yellowfin bream, dusky flathead, striped seapike, tailor and sand mullet. Both boat and shore based fishers surveyed primarily targeted luderick, flathead, bream and mulloway, with a high percentage having no specific fishing target. Steffe and Macbeth (2002) found that species caught were similar to those recorded during a recreational fishing survey conducted in 1990. Australian bass are also a significant recreational species, with a "Bass Catch" event held each year during September, which can attract more than 100 competitors. The *NSW Freshwater Fish Stocking Fishery Management Strategy 2005* permits the stocking of additional bass in the Macleay River (NSW DPI, 2005[1]).

7.3. Boating

The Macleay estuary is well suited to small to medium sized boats, which can access most parts of the estuary and its major tributaries up to the tidal limit. Shallow depths in a number of sections throughout the river limit the passage of larger boats to the lower estuary and out into the ocean. 18
Figure 7 (page 20) shows the key access areas. The following section provides a summary of the boating uses and facilities available within the estuary.

7.3.1. Boating Use

The predominant boating use within the estuary is commercial and recreational fishing. Small, recreational runabout boats of approximately 3 to 4 m in length are the most common vessel on the Macleay River and along the Macleay Arm between Fishermans Reach and Stuarts Point. A significant number of larger boats of up to 8 m utilise the South West Rocks boat ramp and the Macleay Entrance to access the ocean. The commercial fishing fleet, which consists of 14 vessels of up to 15 m in length, operates daily out of Jerseyville to offshore (NSW Maritime, pers. com., 2008).

The number of boats utilising the Macleay estuary varies greatly depending on location, season and other factors such as weather conditions. During peak periods, up to 300 - 400 boat passes through the Macleay Entrance are possible. These are likely to primarily consist of medium to large boats, as the conditions near the entrance can be unsuitable for smaller boats. Other popular areas are generally confined to locations near access points, and include the Macleay Arm and areas near Jerseyville, Smithtown and Kempsey. The more exposed reaches between Kempsey and Seven Oaks, and between Kinchela and Jerseyville can have significant wind waves and hence are less favourable for boating. The peak period is generally between December and March, although there is relatively consistent usage throughout the year.

Whilst the estuary provides opportunities for a range of other boating activities, there are currently low levels of waterway usage compared with other estuaries (DECC, pers. com., 2008). Reasons for this include a lack of adequate area wide tourist facilities, a lack of waterway specific facilities (see Section 7.3.3), a lack of adequate promotion of waterway opportunities and low numbers of tourists spending significant periods of time in the area.

Other than fishing, current waterway activities include the use of power boats such as ski boats and jet skis, water skiing, canoeing, kayaking, rowing, sailing and house boats. A cruise boat also offers site seeing along the lower Macleay estuary. Water skiing is generally not a major activity along the Macleay, although some does occur. The most used areas are upstream of the South West Rocks boat ramp, near Jerseyville, Smithtown and Kempsey, as well as north of the Stuarts Point footbridge along the Macleay Arm. Between 7 and 10 ski boats are estimated to utilise the Macleay Arm during peak periods. Jet skis also utilise the area near Smithtown. The reach upstream of Smithtown and the area near Greenhill upstream of Kempsey have been identified as suitable areas for waterskiing (DECC, pers. com., 2008). The area north of Stuarts Point is also suitable for a variety of water craft and is used by jet skis, ski and wake board vessels, runabouts and canoes.

The reach downstream of Kempsey and around Frederickton was a popular water skiing area but the waterway in this area has largely been blocked by the prolific growth of exotic macrophytes as mentioned in Section 6.2.3, Eutrophication. These weed, mainly Egeria densa and Elodea Canadensis, are Class 5 noxious weeds in NSW but have been identified as providing a beneficial effect in the Macleay by taking up nutrients and hence preventing algal blooms (Section 6.2.3). However, the macrophytes are so dense and widespread that they effectively restrict boating between Kempsey and Frederickton and have a significant impact in the immediate areas both upstream of Kempsey and downstream of Frederickton.

Whilst there are currently no known canoe or kayak hire facilities within the estuary, a number of people who own their own boats use the river (Macleay Valley Coast Tourism, pers. com., 2008). River conditions in the Macleay generally provide relatively safe opportunities for canoeing and kayaking (Kempsey Shire Council website, 2008). In previous years, rowing regattas were held along the Macleay River. However, this no longer occurs. Consultation with the local tourism office has suggested that the river is being used by the Crescent Head surf club for surf boat training and one resident has made a proposal to introduce dragon boat racing (Macleay Valley Coast Tourism, pers. com., 2008).

Similarly, sailing is not a popular activity in the area and there are no sailing clubs. However, those who own their own boats are able to access the river. The northern part of the Macleay Arm near Stuarts Point provides appropriate conditions for sailing, with adequate water depth and width and winds.

Macleay River Houseboats at Kempsey provide houseboat hire for visitors to explore the river between Kempsey and South West Rocks. One or two house boats are usually present on the estuary for various periods of time. However, there is a lack of adequate pumping facilities and moorings.

There are a number of boating restrictions within the estuary, to warn boaters of hazards as well as to minimise environmental impacts such as bank erosion. No wash zones are located near the South West Rocks boat ramp, along a section of the Macleay Arm near the Stuarts Point caravan park, along Spencers Creek, Clybucca Creek and Kinchela Creek, as well as along the south bank of the Macleay between Kemps Corner and Clybucca Creek. 4 knot speed zones occur in South West Rocks Creek and in the Macleay Arm near Stuarts Point. Areas such as the northern part of the Macleay Arm are also protected seagrass areas under the *Fisheries Management Act 1994*, which restricts any activity which could negatively impact upon the seagrass. Toward the upper reaches of the estuary, boating is restricted by shallow water and gravel bars which cross the river. The river is navigable up to Belgrave Falls at the tidal limit for smaller boats.

Whilst boating does not currently appear to have a significant impact on bank stability or instream ecology, there are some areas which are potentially more sensitive to boat use. For example, mangroves along the shoaled area within the Macleay Arm have been uprooted, which is thought to be a result of boat wash (DECC, pers. com., 2008). As a result of extensive shoaling in this area, boats are required to pass close to the banks, which increases the impact of boat wash on bank stability. Should boating use within the Macleay increase, it is possible that additional management of boating is necessary to balance both the environmental needs and needs of waterway users.

7.3.2. Boating Facilities

The majority of river frontage along the Macleay and its tributaries is connected to private land, which restricts river access and is a significant limitation to boating. Whilst there are many private boat ramps and jetties, there are only 9 formal public access points located throughout the estuary, at the following areas:

- Stuart's Point;
- South West Rocks along South West Rocks Creek;
- South West Rocks at The Boat Shed Marina along the Macleay River;
- Jerseyville;
- Kinchela;
- Smithtown;
- Frederickton;
- Kempsey; and
- Greenhill.

An informal public access point is also located along Clybucca Creek at the end of Suez Road (NSW Maritime, pers. com., 2008).

The majority of these access points have limited facilities and are not always located in areas suitable for boat launching. Many do not have toilet facilities, adequate car parking space or picnic areas. Only a few locations have jetties as well as boat ramps, and some jetties such as that at the main Kempsey boat ramp are not necessarily at an appropriate height for the range of boats using the area. Use of the Kempsey boat ramp is also severely impacted by the dense growth of macrophytes that extend from downstream where they effectively restrict navigation to upstream.

A new boat ramp and jetty has been suggested by Council for the Green Hill area upstream of Kempsey. The identified location is at an old quarry site, approximately 4 km upstream of the railway bridge. The river in this location is suitable for water skiing, wide and sheltered, the banks are bedrock or grassed slopes and the land base is close to but isolated from other urban developments. The area is also upstream of the impacts of the macrophyte bloom. Although further investigations are required, development of this area should be of major benefit to boating in the Kempsey area.

The boat ramps at Frederickton and Smithtown are old vehicular ferry ramps with no facilities that are not easy to use for launching. At Frederickton the boat ramp is located in a shallow area with extensive macrophytes and some seagrasses. The land base for the existing ramp will also be affected by the proposed Kempsey By-Pass. As a result there has been a proposal to provide a new boat ramp facility in the Frederickton area. The new ramp and jetty would need to extend far enough into the river such that the water depth was sufficient to enable boats to use the facility without impacting on the seagrasses.

Council has developed a new boat ramp facility at Jerseyville with a landing jetty, parking, picnic facilities and toilets. This facility provides good access to the middle/lower Macleay River but is not preferred to the South West Rocks (Macleay River) ramp, which is closer to the ocean and the Macleay Arm.

The jetty at South West Rocks (Macleay River) is the most popular public access points, with approximately 150 boats being launched each day during the peak season (summer). However, these predominantly consist of offshore vessels. The lack of parking spaces limits the number of vessels using the jetty. Council is currently proposing to increase the size of the parking area, as well as to provide a separate access pontoon. A beaching area is available along the shoaled area immediately upstream of the boat ramp and there are toilet facilities.

The boat ramp in South West Rocks Creek is another popular area for boats wishing to go offshore because of its proximity to the urban area and direct access to the ocean. However, the entrance conditions are difficult during even moderate swells, which limits ramp use. The area is also a popular swimming location. Historically, a significant proportion of the commercial fishing fleet was based at South West Rocks Creek (GHD, 1992). However, much of the Creek is shoaled, restricting navigation particularly at low tide. Consequently, only two boats are still moored in this area (Letcher et. al., 2007).

The Australian National University in consultation with Kempsey Shire Council, GECO Consulting and BAE Services examined a number of different management options for South West Rocks Creek using a decision making tool “CLAM” (Coastal Lake Assessment and Management). Options considered included increased dredging of the entrance. The study found that the options had both positive and negative impacts and in some cases were very costly. A more detailed summary of results is contained in *Back Creek South West Rocks Sustainability Assessment Report* (Letcher et. al., 2007). The facilities at the boat ramp are also limited, having no public toilets, fish bins or picnic areas.

7.4. Passive Recreation

The Macleay Estuary catchment provides opportunities for a number of activities in addition to fishing and boating. Activities include swimming, bushwalking, golf, bowls, tennis, squash, ten pin bowling, horse and greyhound racing, horse riding and bird watching. A number of historical sites also attract both locals and visitors (Kempsey Shire Council website, 2008).

The water quality in the Macleay River and South West Rocks Creek is generally considered adequate for primary contact and there are a few popular swimming areas include near the boat ramp at Kempsey and at South West Rocks Creek (DECC, pers. com., 2008; Kempsey Council, pers. com., 2008). Swimming areas generally require easy access, a relatively gradual decline in base topography, sufficient water quality, protection from high velocity flows, and protection from boating. Within the Macleay, swimming locations are restricted by the lack of public access in safe swimming areas.

There are a number of formal walking trails throughout the estuary, although most of these are concentrated near the coast and in Hat Head National Park. The 2005 tourism plan for the Macleay Valley (ATS, 2005, as described in Section 2.7) suggests that there is scope for additional walking trails which link different parts of the estuary. Picnic areas are also generally located in urban areas and in the National Park. A number of picnic areas do not have sufficient amenities such as toilets.

Facilities for sporting activities and horse and greyhound racing are primarily located in Kempsey, with some facilities also located in South West Rocks.

7.5. Conflicting Usage

The relatively low waterway usage within the Macleay has limited the conflict between different user groups, with some groups actually complementing each other, such as recreational fishing and tourism. Whilst active conflict is not especially apparent, different uses throughout the estuary do impact on each other and also impact upon the environment. Activities such as historical and current farming practices, mining operations and the disposal of untreated sewage have the potential to significantly impact upon waterway activities which rely on good water quality such as the oyster industry and fishing. The following provides a summary of the main conflicting uses within the estuary.

7.5.1. Commercial and Recreational Fishing

Conflict between commercial and recreational fishers appears to be generally limited to the common perception of recreational fishers that commercial fishers are overfishing. Anecdotal evidence has indicated that there is also the perception that the number of commercial fishers have increased due to restrictions in commercial fishing in surrounding coastal areas (Department of Fisheries, pers. com., 2008). However, there is no evidence to suggest that the numbers of commercial fishers have increased, or that they are overfishing (Department of Fisheries, pers. com., 2008). Given that the majority of commercial fishing occurs offshore and the majority of recreational fishing is within the estuary, the conflicts are generally minor.

Historical trends suggest that the commercial fishing catch has remained fairly stable and boat numbers and sizes are limited due to the shallow entrance conditions and lack of mooring facilities (GHD, 1992). There is likely to have been an increase in the number of recreational fishers corresponding with the population increase in South West Rocks and increase in tourism. Should conditions allow a significant increase in either commercial or recreational fishing in the future, it is possible that there will be more conflict between these groups.

7.5.2. Floodplain Use, Fishing and Aquaculture

The major floodplain activities that have the potential to impact on estuary users are farming, human habitation and mining. In many cases the most significant impacts caused by these activities are due to historical practices, such as habitat clearing, extensive drainage works and previous mining practices. However, current activities have the potential to either continue to operate in the environment shaped by this history or to assist in remediation and minimising impacts.

Extensive floodplain drainage works aimed at reclaiming arable land and minimising flood damage has resulted in many adverse environmental impacts such as the exposure of acid sulfate soils and the destruction of wetlands. Wetland species have been replaced by pasture which cannot withstand periods of inundation, causing pasture damage but also creating large bodies of water with low dissolved oxygen levels. Following flood events, runoff re-entering the river and tributaries is therefore of poor water quality and has been associated with fish kills and oyster closures (Macbeth et al., 2002; NSW Food Authority, 2008 [2]).

Poor water quality has been identified by stakeholders as having a significant impact on the oyster and fishing industry (NSW Department of Primary Industries, pers. com., 2008; NSW DPI, 2006; Macbeth et. al., 2002). Human habitation has the potential to impact upon water quality through the discharge of inadequately treated sewage and inadequate development controls. Elevated nutrient levels were observed near wastewater discharges in the River at Gladstone and in the Macleay Arm at Stuarts Point and Grassy Head (Section 5.1.2 and 5.2.2). Nutrient discharges from the Kempsey Sewerage Treatment Plant have been identified as fuelling the major macrophytes growth in the Kempsey to Frederickton area that has effectively prevented boating in that area. There are also concerns about unsewered areas such as at Stuarts Point and from illegal camping such as near the Macleay Entrance (DECC, pers. com., 2008) and the potential for these to cause similar problems in the poorly flushed Macleay Arm.

Historical mining operations in the areas of Hillgrove, Halls Peak, Rockvale, Enmore-Melrose and Mungay Creek have produced significant quantities of mine waste containing heavy metals such as antimony (Sb) and arsenic (As). Much of this waste material has been washed into surrounding waterways, and transported downstream. Whilst most contamination has been observed in localised areas surrounding the mines, in some cases significant transport of heavy metals has been recorded. Elevated Sb and As levels thought to be sourced from the Hillgrove mineral field have been found to occur at the mouth of the Macleay. During periods of flood, contaminated sediment can become mobilised and deposited throughout the floodplain (Ashley and Graham, 2001). Ashley and Graham (2001) found elevated Sb and As levels in the top layer of floodplain sediments which are above background concentrations.

In light of these issues, oyster growers have expressed a desire for improved water quality monitoring, particularly for microorganisms (DECC website – *NSW Water Quality and River Flow Objectives*, accessed 2008). There was also concern that increasing population and tourism has the potential to result in further deterioration of water quality.

7.6. Potential Impacts of Climate Change on Waterway Usage

Increasing temperatures, sea level, and changing rainfall patterns have the potential to substantially change the existing waterway and floodplain land use. It is necessary to plan for these changes to minimise future impacts on the community. Increasing temperatures may affect the viability of the aquaculture and fishing industry, as many aquatic species are vulnerable to increases in water temperatures. Sea level rise will change the location of the saltwater/freshwater boundary, which will affect aquatic habitats and hence may also influence commercially and recreationally important aquatic species. Sea level rise will also affect existing development in flood prone areas, with an increase in the frequency, extent and impact of flooding, as discussed in Section 2.5.5. There is likely to be a loss of beach area along Horseshoe Cove, which is backed by a rocky headland. Boating will be affected as access areas such as jetties, boat ramps and mooring locations would need to be modified to account for elevated ocean levels.

A change in rainfall patterns also has the potential to increase the frequency and intensity of flooding, and hence will impact on existing development. An increase in runoff is likely to increase the transportation of sediment, contaminants and acidic surface soils into waterways. Greater periods of inundation will also increase the frequency of low dissolved oxygen runoff impacting on downstream areas. A reduction in water quality is likely to have a significant impact on the viability of the aquaculture and fishing industry, as well as on recreational use.

8. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1. General

The aim of the Estuary Processes Study was to define baseline conditions for the various estuarine processes operating in the Macleay River Estuary and to examine the interactions between these processes and human use of the estuary and catchment. The purpose of the study was to provide a basis for developing management strategies as part of the next stage, preparation of an Estuary Management Study and Plan.

8.1.1. Summary

Study Area

The study area (shown in Figure 11, page 26) comprises the waterways, foreshores and adjacent lands of the Macleay River estuary from the ocean entrance to the tidal limit, a distance of approximately 54 km. It also includes the tidal reaches of the tributary streams of Kinchela, Belmore and Clybucca as well as the Macleay Arm. The impact of the wider catchment on the estuary was also considered.

Topography

The topography of the Macleay River catchment can be divided into three broad zones: upper valley, mid valley and coastal plains, as shown in Figure 3 (page 4). The upper valley covers approximately 40% of the catchment area and forms part of the New England Tablelands. The area is mostly cleared grazing land with elevations mainly ranging between 900 m and 1200 m. The mid valley covers approximately 35% of the catchment area and is characterised by rugged gorge and steep hill country covered in native forests. The remainder of the catchment encompasses lower hill country and the coastal floodplains (including the estuary). Most of this area is cleared and used for grazing and agriculture.

The Macleay River estuary commences at the tidal limit at Bellgrave Falls, some 8 km upstream of the Kempsey rail bridge. Prior to 1893 the ocean entrance was at Grassy Head, at the northern end of the Macleay Arm. However, a major flood in 1893 breached the sand barrier north of South West Rocks and subsequent entrance training works (including major dredging and breakwall construction) stabilised the entrance at that location. Major stabilisation works, including dredging and bank protection continued until the 1950’s.

Geology

Partially metamorphosed mainly marine sedimentary rocks with a quartz and felspar composition dominate the catchment (73% of the area). Intrusions of granitic rocks with high quartz and felspar content with small amounts of mica occupy about 10% the catchment. These are associated with mineral deposits of Au, Cu, Pb, Zn, Ag, Sb, Sa and Mo. Tertiary age basaltic volcanics and minor sedimentary rocks occupy a further 11% of the area. Deposits of floodplain and estuary sediments cover the remaining 6%.

The materials constituting the floodplains are mostly unconsolidated sand-silt-muds, with gravels prevalent upstream. Silt-dominated levees occur along the river often bordered by muddy to organic-rich backswamps overlying earlier Pleistocene estuarine deposits. The estuary and coastal regions display interactions between Pleistocene to recent barrier beach deposits, estuarine sand-silt-mud and saline to brackish wetland areas.

Climate

The Macleay catchment has a warm temperate to subtropical climate. The climate is influenced by topography, latitude, local differences in altitude, proximity to the ocean, and temperature and precipitation patterns. Hence there are climatic variations between the coastal areas and the rugged mountainous region and tablelands in the upper part of the catchment. In general, the coastal region experiences a warmer and wetter climate than the upper tablelands.

Based on BOM rainfall data the wettest months are February and March for the coastal and mid valley areas and November to January for the tableland region. The driest month occurs in September for coastal and mid valley areas and April for the tablelands. The highest average annual rainfall occurs in the mid valley, followed by the coastal areas. The rainfall has significant spatial variations and needs to be considered within this context but based on the available information the following catchment average rainfalls were adopted:

- 820 mm/yr – Upper Valley – Tablelands,
- 1510 mm/yr – Mid Valley – Gorges and Steep Hills,
- 1260 mm/hr – Lower Valley – Low Hills and Coastal Plains (including the Estuary).

Temperature

Based on BOM data, the highest average monthly temperatures (around 26 °C) occur between December and February and the lowest (around 12 °C) in June or July. In general, minimum temperatures are lower and there is a greater variation between winter and summer temperatures in the tablelands than near the coast. In the lower catchment, temperatures are influenced by the ocean, whereas in the upper catchment temperatures are influenced by elevation and the terrain.

Winds

Again based on BOM data, comparing wind velocities at Kempsey with the nearest low coastal location (at Port Macquarie), approximately 78% of annual wind velocities are less than 10m/s at Kempsey, whereas at Port Macquarie only 36% are less than 10 m/s. The prevailing winds at Kempsey are variable during summer, with most winds from a north easterly through to southern direction, while in winter westerly winds dominate. During both summer and winter there is a significant proportion of time when conditions are calm. The annual prevailing winds nearer the coast (at Port Macquarie) are from the south west and north east. Calm conditions occur for only a small percentage of time.

Evaporation

Using adjusted BOM data from the two closest gauges at Coffs Harbour and Yarras, evaporation for the Macleay estuary was estimated to be approximately 1200 mm/yr.

Climate Change

Based on IPCC research, sea levels are predicted to rise between 0.18 and 0.59 m, from the 1980-1999 average to the 2090-2099 average level across all scenarios. Using a mid range scenario, the projected sea level rise for the east coast of Australia is 0.05 m to 0.1 m above the global average by 2090-2099. The inclusion of potential increases due to ice melt is likely to further increase sea level rise projections by up to 0.2 m. Based on this information and modelling conducted by CSIRO, the Department of Environment and Climate Change (2007) have suggested that sea level rise is expected to be in the range of 0.18 to 0.91 by 2090/2100, with a mid range level of 0.55.

In addition to sea level rise, climate change is predicted to result in a change in rainfall patterns and extreme events. These changes have the potential to increase the occurrence of flooding, and impact upon estuarine processes. However, there is still much uncertainty about the specific nature of such changes on a regional basis. Along the south east coast of Australia, east coast lows are expected to produce a significant proportion of heavy precipitation. However, CSIRO stated that the existing models do not provide sufficient indication of whether the occurrence of east coast lows will increase in frequency as a result of climate change.

Zoning

The entire Macleay River estuary and approximately 25% of the total Macleay catchment are within the Kempsey Shire Council Local Government Area. Zoning categories for the estuary are specified within the Kempsey Local Environment Plan (1987). There are 8 major zoning categories within the estuary. Nearly 90% of the catchment is zoned Rural. Other major zonings include National Parks and Reserves 8(a) which covers approximately 7% of the catchment, and Protection (7) covering approximately 4%. Urban areas (including residential, business and industrial zones) and special use areas occupy less than 1% of the catchment.

Downstream of Kempsey, the majority of the Macleay River is within the Rural zoning. The last 2.5km of the Macleay River and the majority of the Macleay Arm are within areas zoned Protection (7) to the east, with a mix of rural, urban and open space zones to the west.

Land Use

Current land use in the Macleay catchment is diverse. The upper tablelands have been largely cleared for grazing and crops. The escarpment, gorge country and upper hill country are still predominantly vegetated, with the majority of the area being National Park, Crown Land or State Forest although some logging still continues. The floodplain and estuary have mainly been cleared for agriculture including pasture for grazing and crop production. The major towns are Armidale, Kempsey, Walcha, Guyra and South West Rocks. Land use in these areas is dominated by residential, commercial and light industrial development. Other important catchment land uses include fishing, oyster farming, residential development and tourism, and in the past numerous mining operations.

Mining operations within the Macleay have largely ceased, with only one antimony and gold mine remaining at Hillgrove. However, major metal mining was undertaken at Hillgrove, Rockvale and Enmore-Melrose on the tablelands and Halls Peak near Jeogla and Mungay Creek near Willawarrin within the Macleay estuary catchment. Historical mining practices disposed of large quantities of waste material adjacent to waterways that have resulted in elevated arsenic and antimony concentrations extending as far as the ocean.

Tourism

The Macleay estuary is a popular tourist destination and Kempsey Shire attracts some 415,000 visitors each year, particularly in coastal areas. Attractions include the scenic coastline and bushland, historical sites such as Trial Bay Gaol and Smoky Cape Lighthouse as well as a variety of waterways activities. Tourism is a significant industry brining some $90 million into the area each year.

There has been an increase in tourists wishing to explore larger areas and those who want to experience different features of the area. However, Council's Tourism Plan (ATS, 2005) indicates that this type of tourism is not currently well catered for within the Kempsey LGA and that there is a lack of organised tours and a lack of adequate access to different parts of the region. The Plan aims to promote sustainable development and tourism through identifying which areas can withstand increased tourist numbers, and which areas are highly sensitive and require protection.

8.1.2. Conclusions and Recommendations

There are a number of conclusions that can be drawn from the General Catchment assessment:

- In terms of most catchment characteristics such as topography, geology and climate, the Macleay River catchment is similar to other NSW North Coast Rivers, particularly the Hastings and Manning Rivers.
- The Macleay Catchment differs from many other North Coast Rivers in relation to the large number of metal mines that have operated in the catchment in the recent past. This has affected water and sediment quality.
- The Macleay Estuary differs from other North Coast Rivers in that the location of the entrance and hence the length of the estuary has recently (geologically) shortened substantially. This affects the estuary hydrodynamics and sediment movement.
- Rural and protection zonings over most of the estuary catchment and alone the foreshores helps to control development.
- The Macleay Catchment has limited opportunities for tourists to explore larger areas. This could affect tourist numbers and hence waterway use.
- Climate Change will impact on the hydrodynamics of the system as a result of sea level rise and increased storminess, particularly in the lower estuary.

8.2. Hydrodynamics

The hydrodynamics of the Macleay estuary has two main driving forces, fluvial inflows and ocean tides. Wind driven currents and waves can also have localised impacts. Hydrodynamics are important because the inflow, mixing and exchange of fluvial and tidal waters impacts on other estuarine processes such as bank erosion and sedimentation, salinity levels and water quality, nutrient and contaminant distribution, ecosystem life cycles and human use.

As a result of the hydrodynamic interactions, three process zones are formed that reflect the differing degrees of fluvial and tidal influence. Fluvial processes dominate in the upper part of the estuary from Belgrave Falls as far downstream as Kinchela, after which there is a transition to tide dominated processes, which dominate downstream of Jerseyville to the ocean entrance.

8.2.1. Summary

Numerical Modelling

A combination of hydrologic (rainfall-runoff) modelling and hydraulic open channel modelling calibrated to existing river flow and water level data was used to examine the hydrodynamics of the estuary for both fluvial and tidal conditions. The hydrologic WBNM model was used to model catchment inflows. A RUBICON quasi-two dimensional hydraulic model was used to examine food flows and a combined one and two dimensional RMA-2/11 numerical model was used to model tidal flows and water quality. All the models were calibrated to existing data as far as possible.

Fluvial Flows

Fluvial inflow data for the Macleay shows that the average annual discharge is around 2,150 Mm^3, although this can vary by between 8% and 240% anually. The flood data shows that the 50% AEP peak flow at Belgrave Falls was in the order of 300 times greater than the median flow and the 1% AEP peak flow was 1400 times greater. However, the modelling showed that even for a comparatively small event like the 50% AEP, large flow volumes were diverted to storage on the floodplain and into the tributaries. The modelling showed that the 1% AEP was some four times greater than the 50% AEP at the top of the estuary, at Belgrave Falls, but in the order of 2.5 times greater at the ocean entrance.

Tidal Flows

The data showed that for existing conditions there was a substantial decrease in tidal range through the entrance as a result of entrance losses associated with high velocities, turbulence and bed friction. The mean spring tidal range fell from 1.35 m at the ocean to 1.0 m just inside the entrance (at South West Rocks). Tidal flows then remain constricted by the channels until around Smithtown (where the fluvial dominated channels are quite wide but the tidal flows are beginning to get quite small).

In general, the study showed higher peak flows for in flowing (flood) tides than for out flowing (ebb) tides, with the out flowing tides longer and more constant. The mean tidal prism at the entrance was 11.4 Mm^3, slightly lower than the neighbouring Hastings River, which is relatively similar in size. By comparison, the significantly larger but partially trained Manning River entrance has a mean tidal prism of around 10 Mm^3 and is significantly less efficient than both the Hastings and Macleay Rivers.

Comparison of Fluvial and Tidal Flows

To provide a better understanding of the relative impacts of fluvial and tidal flows throughout the estuary a comparison has been made between the mean spring tide and the 50% AEP flood. Note, on average there are about 140 tidal ranges greater than the mean spring range each year but only one 50% AEP flood every two years (ie the tide occurrence is some 300 times more than the flood).

The data showed that floods with magnitudes around the 50% AEP have flows that are only two to three times greater than spring tidal flows in the lower estuary, but increase to around 10 times at Smithtown and 50 times at Kempsey. This indicates that tidal flows dominate the entrance area and Macleay Arm but that floods play an important role, especially in the upper reaches of the estuary. Larger floods such as the 1% AEP with several times larger flows have a major effect throughout the estuary, but particularly in the upper estuary.

Water Balance

An annual water balance is an estimation of the volume of water from different sources that passes a point in the estuary. By identifying the dominant source and the balance between the sources it can provide useful information on the processes operating at that location. Comparison was also made between current conditions and the conditions that would have existed prior to major development.

The analysis showed that flows at the entrance are dominated by tidal flows 75%, with catchment inflows representing 24% and direct precipitation on the estuary <1%. The predevelopment analysis was similar, with 77% tidal and 22% fluvial.

Tidal Flushing and Salinity

Flushing times for key locations in the estuary were determined by calculating the e-folding times. The e-folding time provides an indication of flushing within an estuary and can be used to identify areas which may be susceptible to water quality issues. It should be noted that the e-folding time only considers tidal flushing, which only plays a minor role in the upper reaches.

The results show as expected that e-folding times increase as you move up the estuary. Within 7 km upstream the entrance the waters are well mixed and the e-folding time is lower than 5 days. Further upstream the tidal mixing decreases, resulting in 30 days or six times higher e-folding times a further 2.5 km upstream. The upper reaches of Clybucca and the Macleay Arm requires some 50-60 days until the threshold concentration is reached. Much higher flushing times occur for the Jerseyville anabranch, where waters get trapped and also for the estuary upper reaches that are a long way from the ocean.

Floodplain Discharge Flushing

Catchment waters stored behind floodgates can have low oxygen levels and/or high acid levels. The RMA model was set up to replicate stored catchment water discharges at known locations so that different floodplain release scenarios could be examined as part of subsequent Management Study considerations. For the purposes of this study, two locations were modelled, the entrance of the Kinchela Creek and the head of Clybucca Creek. The results of the model runs compared well with anecdotal reports but far more scenarios need to be examined as part of the Estuary Management Study so as to develop management strategies.

Waves

Waves are important mechanisms for generating foreshore erosion and increasing water turbidity, and can contribute to mixing. Within an estuary the main generating sources are local wind waves and boat wash.

Local wind generated waves tend to be the dominant wave type across the estuary. As part of the study an analysis of wind generated waves was undertaken for 23 sites along the estuary where erosion was known to occur. The analysis showed that the highest wave energy occurs at two locations between Jerseyville and Kinchella and along the Macleay Arm. These locations have a relatively long fetch length allowing for larger wave generation and being close to the coast are influenced by the stronger coastal winds. However, these locations only experience minor erosion.

An analysis of boat generated waves was also undertaken for the same 23 locations examined for wind generated waves. The highest energy was calculated for the area between Jerseyville and Spencers Creek and along the Macleay Arm, although again only minor erosion was recorded at these locations.

For both wind and boat generated waves, sites with the highest estimated wave energy did not correspond with locations exhibiting major erosion. However, erosion is also dependent upon the soil constituents. As a result, more severe erosion can occur in areas with highly erodable foreshores even if wave energy is lower. Previous studies in other rivers suggest that wave energy is not always the primary cause of bank erosion, with stream flow also being the major cause. Other possible causes of erosion include cattle access and local runoff causing slumping in areas devoid of vegetation.

Climate Change

As discussed in the Catchment summary, climate change is likely to have a significant impact on the hydrodynamics of the Macleay Estuary. Any increase in mean ocean tide levels would result in a corresponding increase in water levels inside the estuary and an increasing tidal range/extent. Increasing ocean levels would also have the potential to change the entrance conditions, which significantly influence the exchange of fluvial and tidal flows. Assuming shoaling at the entrance does not increase, tidal exchange and the average annual water balance would increase. The impact of tidal storms on the surrounding floodplain would also increase, as a more open entrance would allow elevated ocean levels due to storm surge and wave setup penetrate into the estuary.

Any increase in rainfall would increase the level of catchment runoff and the volume of fluvial flows in the estuary water balance. The result would be an increase in the water balance, but as mentioned above could also include some increase in tidal flows. Any decrease in rainfall would be associated in decreased catchment runoff and a smaller water balance.

8.2.2. Conclusions and Recommendations

There are a number of conclusions that can be drawn from the Hydrodynamics assessment in relation to human impacts:

- The estuary can be divided up into three zones based on the hydrodynamics, a Fluvial Zone from Belgrade Falls to Kinchela, a Transitional Zone from Kinchela to Jerseyville and a Marine Tidal Zone from Jerseyville to the ocean.
- Substantial energy losses occur at the ocean entrance due to the high velocities, turbulence and friction effects, but these are less for the fully trained entrance than when compared to predevelopment conditions or partially trained entrances like the Manning River.
- The peak inflowing tide is higher than the out flowing tide, which is longer and flatter.
- Tidal exchange is the main flow mechanism in the lower river and the Macleay Arm but has very little impact in the upper river above Kinchela or in the Clybucca Anabranch.
- Fluvial flushing is the main flow mechanism in the upper river and creeks.
- The release of low DO or pH ponded waters from behind floodgates can cause substantial ecological damage. The RMA model as established allows for different discharge scenarios to be examined as part of the Management Study.
- Sea level rise will affect the hydrodynamics of the system and this is likely to affect sediment transport, water quality and ecology throughout the estuary,
- Increased flooding due to Climate Change could occur due to increases in rainfall and/or spatial/temporal variation.

8.3. Sediment Dynamics

8.3.1. General

Sediment dynamics describe the formation, distribution and movement of sediments within an estuary system. The distribution of different sediment types (facies) helps define the fluvial, transitional and marine process zones within the estuary. Further, the morphology (shape) of estuary channels, banks and floodplains form in response to sediment movement mechanisms, and have a major impact on human use of the waterway and foreshores.

Sediment movement dynamics in the Macleay River estuary are primarily driven by tidal and fluvial (flood) flows, although wind and wave movements and human impacts (land management practices, boat wash, past channel dredging and bank training) also have localised effects.

8.3.2. Summary

Sedimentology

The widespread substrate of the Macleay catchment typically gives rise to quartsofelspar lithic gravel deposits in the tableland streams and cobbles and boulders in the gorge country but finer sediment fractions dominate in the lower reaches dominated by quartz and felspar grains and lithic material. To help determine and quantify the distribution of sediments through the Macleay

Estuary 59 bed sediment samples were collected and analysed. Based on this analysis the sediments were divided into three broad facies:

- Beach and Nearshore Marine Sands,
- Reworked Coastal Sands,
- Fluvial Sands.

The analysis showed that the distribution was similar to other major NSW river estuaries with fluvial sand deposits along the upper estuary reaches and coastal/marine sands along the lower reaches. However, the Macleay differed from most other similar sized estuaries in that the fluvial sediments extended to within a couple of kilometres of the ocean entrance. Most other major river estuaries have a wide band of reworked coastal sands mixed with some fluvial sand along the lower coastal zone. However, in the Macleay the Transitional Zone is dominated by fluvial sediments, with a very short zone of mixed marine, coastal and fluvial sediments near the confluence between the river and the Macleay Arm.

The reasons for the differences is not related to significantly different tidal or fluvial hydrodynamics or sedimentology, but rather to the relatively recent (geologically) change in the location of the river entrance and the effects of the entrance training works on beach littoral zone sand movements over the period since the entrance location changed.

Existing Bed and Bank Conditions

Bank erosion not only causes a loss of valuable foreshore land, it also contributes to sedimentation and shoaling in the estuary and increases the concentration of suspended solids in the water column. Bank erosion can be caused by a number of different processes including fluvial scour, waves, the loss of riparian vegetation and cattle access. An assessment of bank erosion was undertaken as part of the Data Compilation Study. Bank erosion severity, failure mechanism and dominant processes were recorded for each location where erosion occurred for more than 20 m in length.

The Fluvial Zone has the most severe bank erosion although 90% is stable (22% of this being stabilised by bank revetment). The dominant causes of erosion were found to differ. The upper reaches were dominated by fluvial processes with significant erosion often resulting from major floods with an increased risk where vegetation was cleared and cattle had river access. The middle reaches between Kempsey and Seven Oaks were predominantly stable with extensive rock protection. Isolated small sections of toe scour and fluvial erosion were observed. The lower fluvial reaches were the most active with significant (mainly wind) bank erosion at Kinchela Bend (3 km) and Fattorini Island (0.5 km) where the erosion was in a channel constriction and is impacted by both flood currents and ongoing wave erosion.

The Transitional Zone was the second most unstable area of bank erosion although there was no severe erosion and only 1.2 km of moderate erosion and 6.3 km of minor erosion. However, some 43% or 30 km of bank has been rock protected. The most significant erosion along the main river was at Pelican Island where waves were eroding a layer of sands and silts. Erosion along Clybucca Creek was mainly along the outside of bends indicating a current induced process, although this appeared to be maintained by (wind and boat) waves.

The marine tidal zone was the most stable, with only 6% (3.8 km) being assessed as having minor erosion. Of the stable banks 23% (16 km) had been rock protected. The bank heights in this zone were very low and the erosion appeared to be the result of wind and boat waves.

River Planiform Changes

River planiform describes the shape and location of a river as viewed above. Rivers naturally change over time, adjusting to controlling factors such as different flows, sediment size and supply rates, bank characteristics, geology and catchment slope. For example, there is a natural tendency for rivers to increase in sinuosity as the outside bends become eroded due to higher velocities, and inside bends undergo deposition. Planiform changes can provide an indication of how much a river has moved over time, and how stable it is. Morphological variables describe channel form and include features such as channel width, mean depth, thalweg (maximum depth), channel slope and sinuosity.

Human activities can have significant impacts on river morphology. For example, land clearance and cattle access can increase bank erosion and sediment transport into the river. This can decrease sinuosity and hence increase slope and velocity in an attempt to transport the excess sediment down the river.

In order to examine the planiform changes for the Macleay River, aerial photographs from 2003 and 1956 were compared with historical parish maps from 1907 to 1913. This examination showed that although there had been significant localised bank movements, the majority of Macleay River Estuary had not changed significantly over the last 100 years, suggesting it is relatively stable. The most significant changes had occurred in the lower estuary and along the coast, primarily the movement of the estuary mouth from Grassy Head to South West Rocks following a major flood in 1893. This resulted in a westward shift and contraction in river width along the Macleay Arm as a result of infilling by aeolian sand from the beach dunes (and some dredged sand deposition). The construction of breakwalls along the new entrance intercepted much of the northerly littoral zone sand movement, resulting in prograding of the coastline (seawards extension) to the south of the breakwalls and erosion/recession of the northern beach.

Extensive rock revetment along 66 km of river banks has restricted bank erosion and movement between 1956 and 2003. In areas that were free to adjust, the length and severity of the erosion is low when compared with similar nearby river estuaries. The erosion that is occurring appears mainly to be current initiated and then maintained by a combination of wind and boat waves. This is more likely to occur where the soils are highly erodible.

Whilst rock revetment provides local bank stabilisation, it does not prevent the river from adjusting. It is not known how the river will continue to adjust to past changes. However, the most significant impacts are likely to be caused by major flooding, climate change, surrounding land practices and direct modifications to the river. Historical land practices have already resulted in extensive clearing of vegetation along the banks. This has the potential to increase rates of bank erosion. Unless revegetation of the banks and the exclusion of cattle occurs, sedimentation and bank collapses are likely to continue.

8.3.3. Conclusions and Recommendations

There are a number of conclusions that can be drawn from the Sediment Dynamics assessment in relation to human influences:

- The estuary can be divided into the same three zones as for the hydrodynamics, a Fluvial Zone from Belgrade Falls to Kinchela, a Transitional Zone from Kinchela to Jerseyville and a Marine Tidal Zone from Jerseyville to the ocean.
- Bank erosion along the Macleay is not severe when compared to many NSW coastal rivers, mainly due to the extensive bank protection works undertaken in the past.
- Ongoing bank erosion is continuing but the causes are very variable.
- Planiform changes in the last 100 plus years indicate that although there have been significant localised bank movements these changes have not altered the overall sediment dynamics except in the lower estuary/entrance area where there were major changes associated with the movement and stabilisation of the entrance from Grassy Head to near South West Rocks.

8.4. Water and Sediment Quality

8.4.1. General

Water quality can be affected by a number of different processes. The hydrodynamics of the estuary can influence flushing characteristics and hence mixing of the estuary, the salinity structure, and how quickly nutrients and contaminants are distributed as well as removed. Rainfall patterns and the surrounding land use can influence the volume and quality of runoff

8.4.2. Water Quality Summary

Maintaining adequate water quality is essential for the health and functioning of aquatic species as well as for human use. Guidelines such as ANZECC and the OISAS Water Quality Objectives provide recommendations on the amount of different constituents that are unlikely to result in adverse biological and ecological impacts. Typical parameters used to measure water quality include salinity, dissolved oxygen, temperature, total suspended solids, nutrients, pH, toxicants, chlorophyll-a, faecal coliforms, and the presence of any pathogens.

Water quality can be affected by a number of different processes. The hydrodynamics of the estuary can influence flushing characteristics and hence mixing of the estuary, the salinity structure, and how quickly nutrients and contaminants are distributed as well as removed. Rainfall patterns and the surrounding land use can influence the volume and quality of runoff during storm events. The drainage of acid sulfate soils for farming and other land uses can reduce pH in the estuary, and the planting of flood-intolerant pasture species can cause deoxygenation through the decomposition of organic material. Wastewater discharge can increase nutrient concentrations and algal blooms, and bank instability can increase total suspended solids. Mining operations have also resulted in elevated concentrations of arsenic and antimony within the Macleay River, its tributaries, and sediments in the surrounding floodplain.

Poor water quality can adversely impact on aquatic habitats and aquatic species. Many aquatic species play an important role in cycling nutrients and maintaining adequate water quality. Other species such as riparian vegetation and birds which prey on estuarine fish may be affected by poor water quality. Commercial activities reliant on aquatic species such as aquaculture and fishing would be affected, as would primary and secondary contact use of the estuary such as swimming and boating.

Sampling Program

As part of the study 12 monthly sampling runs were undertaken from September 2006 to August 2007 along both the Macleay Arm and main arm of the Macleay Estuary. Sampling runs in the Macleay Arm were usually completed within about 1 hour and were timed to start at the ocean entrance about 1 hour before high tide. Sampling runs in the main river were usually completed within about 3 to 4 hours and were timed to start at the ocean at about high tide and progress upstream with the high tide crest to Kempsey. In the Macleay Arm, 5 samples were collected at set locations. In the Macleay River, samples were collected at different salinity concentrations, from seawater to freshwater along the estuary and set locations between Smithtown and the Kempsey when saltwater did not intrude that far.

Salinity, Dissolved Oxygen, pH and Suspended Solids

Flushing times were dependent upon the flow of freshwater from upstream and tidal patterns. Over the study period flushing times ranged from 3 days to 57 days depending on flow. Salinity profiles varied from highly stratified to well mixed and the salt/freshwater interface was upstream of Kempsey or pushed out to sea. Dissolved oxygen concentrations were generally within ANZECC guidelines, except after flood events when they dropped due to the decomposition of organic material. Near the macrophyte beds in the upper estuary, oxygen was supersaturated, probably a result of the high rates of primary production. pH decreased along the salinity gradient from the saltwater to fresh and decreased after high flows. An increase in pH occurred near the macrophyte beds, consistent with supersaturated dissolved oxygen concentrations. pH values were generally within the recommended values for oyster growth. Total suspended solids were higher in the lower estuary due to wind resuspension, and also increased after a flow event.

Nutrient Levels and Sources

Total nitrogen concentrations were generally below ANZECC guidelines. They were higher in the lower estuary and Macleay Arm, especially during summer. This was probably due to the presence of seagrass beds. Concentrations exceeded ANZECC levels in the upper estuary after high flow events due to increased runoff. Nitrate and ammonium concentrations exceeded ANZECC levels near the Gladstone wastewater plant, although were well assimilated by the macrophyte beds. Low nitrogen levels throughout the estuary suggest that the estuary was nitrogen limited.

Total phosphorus concentrations were also below the ANZECC guidelines, and were higher at the ocean end, suggesting an ocean source. Concentrations were also higher after increased flow from runoff. There was some uptake of phosphorus by the macrophyte beds, although the estuary is unlikely to be phosphorus limited. The Macleay Arm, especially near Grassy Head and Stuarts Point were found to experience higher phosphorus concentrations during summer, possibly due to effluent from septic tanks or release from sediments.

Chlorophyll-a levels were found to be generally around the lower limit, with a peak downstream of Gladstone Wastewater Treatment Plant. Concentrations are generally lower immediately after high flows, followed by an increase due to increased nutrients transported from the floodplain. Phytoplankton blooms were more frequent during summer, and it is recommended that additional research is conducted into the cause of summer phytoplankton blooms.

Comparison of nutrient concentrations with those measured during previous studies indicated that generally there were minimal differences, although there appears to have been an increase in nitrate and dissolved inorganic phosphorus concentrations from runoff during high flow events.

Preliminary research into the potential impact of septic tanks on water quality has indicated that there is the potential that there are increased nitrogen levels due to septic tank effluent in the Macleay Arm. However, the results are inconclusive, and it is recommended that further research is conducted.

Carbon, nitrogen and phosphorus nutrient budgets were developed for the estuary to determine the major nutrient sources and sinks. The budgets highlighted the importance of benthic production as a carbon source, which supplies higher trophic levels such as fish. Benthic production requires adequate light penetration (low Total Suspended Solids and low chlorophyll-a), and low nutrient concentrations. The main nitrogen and phosphorus inputs are from runoff and in the dry season the largest nitrogen input is from wastewater. Benthic denitrification was the largest output of nitrogen, which relies on low algal production. The main phosphorus output is through burial.

Biogeochemical and Physical Processes

The main biogeochemical and physical processes within the estuary are largely depended upon flooding. These processes in turn influence the ecological health of the estuary. During a flood, freshwater can extend into the ocean and there can be substantial transport of sediment that may be deposited either within the estuarine basin or delivered to the continental shelf. Floodwaters from the surrounding floodplain may be deoxygenated and contain higher concentrations of sulphides, nutrients, and sediment containing antimony and arsenic. Additionally, acid sulfate runoff can result in a reduction in pH. Floods can create habitat diversity, but can also cause disturbance, a temporary loss in habitat and loss of food supply due to poor water quality.

Immediately following a flood, a highly stratified salt wedge develops, which becomes partially mixed and then vertically homogeneous. Deposition of sediment at the salt/freshwater interface is likely to occur and oxygen levels remain low due to the decomposition of nutrients. The estuary is vulnerable to algal blooms during this stage.

During dry seasons, the estuary remains vertically homogeneous due to low freshwater flows.

Nutrient levels are generally low in the upper estuary due to uptake by macrophyte beds, although elevated algal biomass concentrations can occur adjacent to and downstream of the Gladstone wastewater discharge and adjacent to Grassy Head and Stuarts Point.

8.4.3. Sediment Quality Summary

Significant areas within the Macleay estuary catchment and floodplain contain sediments with elevated antimony and arsenic concentrations. The majority of the estuary is also classed as being of high acid sulfate soil (ASS) risk. Acidic and contaminated sediments have an impact on the ecology of the floodplain, and can also reduce water quality and impact upon in-stream ecology. Arsenic is toxic to both animals and plants. The environmental behaviour of antimony is less well known, although it is expected to behave similarly to arsenic as it has similar chemical properties. Further research is recommended to investigate the metabolism of different forms of arsenic and antimony.

Metal Contamination

The Macleay catchment has naturally elevated concentrations of heavy metals and has a number of major mineralised regions, the most significant being the Hillsgrove region. Contamination of sediments and waterways can result from natural processes such as erosion of mineralised rock or from mining processes such as waste disposal practices. Land uses which remove vegetation and increase erosion can increase the transport of sediment from the floodplain to the Macleay River and its tributaries. Mining of arsenic and antimony has resulted in a dispersion train as long as 300km from Hillgrove to the ocean.

There has been some preliminary research into the bioavailability of arsenic and antimony in the Macleay catchment. Elevated arsenic and antimony concentrations have been found in pastures but investigations into the impact of arsenic on cattle found that there was no detectable impact on cattle grazing on arsenic contaminated tailings. The studies also showed some uptake of arsenic by algae and some uptake in oysters. Studies have also found that there was a greater uptake of antimony compared with arsenic in riparian vegetation but no measurable uptake of antimony in oysters.

As part of the current study, analysis of four sediment samples indicated that all arsenic concentrations were below the ISQG – low guidelines. In three samples antimony concentrations were above the ISQG – low value but below the ISQG - high value. A higher percentage of arsenic (29%) was found to be leachable and hence potentially bioavailable compared with antimony (<16%). Both arsenic and antimony are more likely to be mobilised at pH above 6-6.5 and below 3.

Acid Sulfate Soils

ASS cover a significant area of the Macleay estuary catchment. Key affected areas include Yarrahapinni, Collombatti – Clybucca wetlands, Belmore Swamp, Frogmore area, Kinchela Swamps and Raffertys wetland. ASS can reduce the pH of soil and waterways, which can make them toxic to plants and animals.

8.4.4. Conclusions and Recommendations

The following conclusions and recommendations can be drawn from the Water and Sediment Quality assessment:

- Water quality parameters were generally within ANZECC guidelines, with exceptions being low dissolved oxygen after flood events, and elevated nitrogen concentrations in the upper estuary after high flows. Elevated nitrogen and ammonium concentrations were also observed near the Gladstone wastewater discharge, although nutrients are generally assimilated by the macrophyte beds.
- It is recommended that the incorporation of additional nutrient removal as part of the wastewater treatment process is investigated, to reduce nutrient concentrations and reduce the expanse of macrophytes in areas designated for boating use.
- Phytoplankton blooms were found to occur more frequently over summer. It is recommended that further investigation is undertaken to determine the causes of these blooms, and possible ways to minimise them.
- Preliminary investigations indicate that septic tank effluent may be impacting upon water quality in the Macleay Arm. Further research into the possible impact of the effluent is recommended.
- Nutrient budgets have highlighted the importance of benthic production, which requires low total suspended solids and nutrient concentrations to minimise algal blooms.
- Acid sulphate soils and arsenic and antimony contamination affect significant areas of the Macleay estuary as well as the wider Macleay catchment. These may negatively impact upon water and sediment quality, as well as the ecology of the estuary.
- More research is recommended into the bioavailability of different forms of arsenic and antimony, as well as the potential impacts upon the ecology and the commercial fishing industry.

8.5. Ecological Characteristics

8.5.1. Summary

In total 46 threatened fauna have been found to occur within the Macleay estuary, of which 7 are endangered and 39 are vulnerable under the NSW Threatened Species Conservation Act 1999. The majority of threatened species are mammals and birds. Birds are considered to be the most likely to use the estuary for roosting, nesting, foraging or their entire life cycle. A number of migratory birds also utilise the estuary during the non-breeding season.

Endangered ecological communities and protected habitat areas have been identified within the estuary. Endangered ecological communities within the estuary induce the following:

- Coastal Saltmarsh;
- Freshwater Wetlands on Coastal Floodplains;
- Subtropical Coastal Floodplain Forest;
- Swamp Schlerophyll Forest on Coastal Floodplains;
- Swamp Oak Floodplain Forest; and

- River-flat Eucalypt Forest.

Protected habitat areas include those listed under State Environmental Planning Policy 14 Coastal Wetlands, and State Environmental Planning Policy 26 Littoral Rainforests. Fourteen habitat areas of particular significance were identified as part of the study (listed below), the majority of which are freshwater wetlands.

- Christmas Creek (north of Kempsey);
- Barnetts Lagoon;
- Old Pola Creek;
- Cooroobongatti Swamp;
- Swamp W and SW Clybucca;
- Swamp NE Kinchela;
- Swamp SE Kinchela;
- Swamp S Jerseyville;
- Clybucca Creek;
- Andersons Inlet;
- Pelican Island;
- N of Rainbow Reach (between the Macleay River and Clybucca Creek); and
- Shark Island and adjacent channels.

Only one vulnerable aquatic species (Black Cod) is known or considered likely to utilise the Macleay estuary. The Black Cod inhabits estuaries along the north coast of NSW, and it is generally found in rocky reef areas. It is therefore likely that its occurrence within the Macleay estuary would be limited to rocky areas in the lower estuary. A number of commercially and recreationally significant species are also found in the estuary, which rely on adequate aquatic habitat and water quality.

The ecological health of the estuary is influenced by other estuarine processes, including hydrodynamics, the location of the saline/freshwater interface, water quality, sediment dynamics and quality, and human usage. Hydrodynamics can influence water quality as well as habitat health and availability, whilst the location of the saline/freshwater interface can influence the extent of saline habitat. Flooding can have both a positive and negative impact by creating new aquatic habitat in wetland areas, whilst removing habitat for terrestrial species.

Water and sediment quality have a direct impact on the health of aquatic species, and can also impact upon habitat used by terrestrial species. Sediment dynamics such as bank erosion can reduce light penetration in the water column, which can impact negatively upon aquatic species. Water and sediment transport from the floodplain can also affect aquatic health by increasing nutrient concentrations, lowering dissolved oxygen concentrations, and reducing pH.

Human usage of the estuary has had the most significant impact on the ecological health of the estuary. Development has resulted in a loss of habitat, and increased transport of sediment, nutrients and pollutants. Mining activities have increased arsenic and antimony contamination of waterways and their surrounding floodplains. Bank stabilisation works and dredging have also influenced sediment dynamics, and can increase bank erosion and hence loss of riparian habitat in unprotected areas.

8.5.2. Conclusions and Recommendations

The following conclusions and recommendations can be made from the Ecological Characteristics assessment:

- The ecology of the Macleay estuary has been substantially altered as a result of land clearing, development, the construction of floodplain mitigation structures and drainage systems, and other human uses. However, the existing ecology appears to be relatively stable, and adequate water quality has helped maintain in-stream ecology.
- Of the 46 threatened terrestrial species likely to occur in the Macleay estuary, the majority are birds and mammals. Birds are considered the most likely to rely upon estuarine habitat.
- Only one vulnerable aquatic species is considered likely to occur within or near the Macleay estuary (the Black Cod). This species is more likely to be found near the rocky areas in the lower estuary.
- The estuary supports a number of commercially and recreationally significant aquatic species. Commercial catch has remained relatively stable compared with other NSW estuaries, indicating that stocks are likely to be above the threshold required to sustain the population.

8.6. Waterway Usage and Facilities

The lower Macleay River and surrounding floodplain support a wide variety of commercial and recreational uses, including fishing, aquaculture, agriculture, boating, swimming, walking, and tourism. Both the oyster and commercial fishing industry are locally significant, producing approximately 2% of the total NSW production. Existing recreational usage of the Macleay estuary waterways appears to be limited by a lack of adequate river access and facilities. There is also scope for improved access, facilities and promotion of the surrounding catchment, to encourage both the local community and tourists to utilise and appreciate the natural and cultural attractions. Future development and increases in usage should be planned for, to ensure that it occurs in a sustainable manner. This requires consideration of appropriate locations for different uses, any necessary restrictions on usage, and the ongoing monitoring of impacts. Historical and current land uses have already significantly impacted upon the health and functioning of the estuary. It is necessary to engage the community to address existing issues such as riparian habitat loss, the loss of wetland and flood tolerant vegetation, and acid sulfate soils. The potential impacts of climate change should also be considered.

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