Climate Change and the Fisheries of NSW - a Background Paper for NSW Department of Primary Industries

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Introduction

The Australian coastal economic/fishing zone is the third largest in the world and covers more than 9 million km^2 (AFMA, 2007). In addition approximately 90 % of the Australian population of 20 million live within 120 km of the coast (Voice *et al.,* 2006).

Climate change is already affecting Australian marine life and consequently Australian fisheries and aquaculture (Newton, 2007). However, current Australian climate change research, expertise and knowledge in the fisheries area are at best limited and patchy.

Australian Marine Climate Change Projections

International and Australian global climate models all predict at least a doubling of pre-industrial levels (280 ppm) of global atmospheric CO^2 by the end of this century. Climate change projections from the CSIRO Mk 3.5 climate model of Australia's marine area by 2070 are summarised in Table 1 (Hobday *et al.,* 2006).

The CSIRO model predicts that the greatest warming in the Southern Hemisphere oceans will be in the Tasman Sea associated with a strengthening of the East Australian Current (EAC). This feature is present in all IPCC climate model simulations and is driven by a southward migration of the high westerly wind belt south of Australia. Warming will not only affect surface waters, but will also penetrate deep into the ocean, warming waters down to 500 m and beyond. This will have major consequences for bottom-dwelling fish and invertebrate communities. Climate change will also substantially modify other physical variables important for regulating marine ecosystems including incident solar radiation (through cloud formation), winds and the mixed layer depth. Increases in atmospheric CO^2 levels will make the ocean more acidic, adversely affecting many organisms that use calcium carbonate for their skeletons and shells, including corals, molluscs and some phytoplankton species.

Table 1: Projected changes in physical and chemical characteristics of Australia's marine area by 2070 from the CSIRO Mk 3.5 model (From Hobday *et al.,* 2006).

Physical climate change indicators	Projected climate change impacts by 2070
Sea surface temperature	Waters around Australia will warm by 1-2°C, with greatest warming in SE Australia/Tasman Sea due to strengthening of EAC.
Temperature at 500 m depth	Warming of 0.5-1°C
Incident solar radiation	There will generally be more incident solar radiation on the sea surface in Australian waters. The increase will be between 2 and 7 Wm^{-2}.
Mixed layer depth	Almost all areas of Australia will have greater stratification and a shallowing of the mixed layer

	by about 1 m, reducing nutrient inputs from deep waters.
Surface winds	An increase of 0-1 ms^{-1} in surface winds will occur.
Surface currents	A general decline in the strength of surface currents of between 0-1.2 ms^{-1} is expected.
pH	A decline in pH by 0.2 units is expected.

Expected impacts on aquatic life

The impacts on aquatic systems especially marine systems, of the above have been comprehensively analysed (to the extent permitted by available data) in two recent reviews commissioned by the Australian Greenhouse Office (Hobday and Matear (eds), 2005 and Hobday *et al.,* 2006). These and other data from the Bureau of Meteorology (2007), Fisheries Research and Development Corporation (2007), Hennessy *et al.,* (2007) World Wildlife Fund (2007) are summarised in Table 2.

Table 2: Some likely impacts of climate change on Australia's oceans, coasts and rivers, as exemplified by biophysical change from climate drivers [Australian Greenhouse Office (Hobday and Matear (eds), 2005 and Hobday *et al.,* 2006), Bureau of Meteorology (2007), CSIRO (2007), Fisheries Research and Development Corporation (2007), Hennessy *et al.,* (2007) World Wildlife Fund (2007)].

Variable	Impact
Sea level rise and storms	• a rise in sea-level from thermal expansion of the ocean and glacial melt, and increased frequency or intensity of extreme storms leading to higher risk of inundation and flooding. • shoreline erosion and realignment leading to loss of amenity or damage to assets (natural and human).
Warmer ocean temperatures	• increased frequency of coral bleaching events (present models project the Great Barrier Reef will warm by 2 to 5° C by 2100). • potential impacts on biodiversity by affecting the distribution and reproductive patterns of marine organisms, and consequently food web dynamics (productivity).
Ocean acidification	• increased CO_2 concentration in sea water is altering ocean chemistry, making it more difficult for calcitic organisms such as coccolithophores, corals and molluscs to grow and function.
Decreased rainfall and drought	• warmer temperatures will cause greater evaporation, increasing the severity of drought for a given decrease in rainfall.
Increased river temperatures (freshwater)	• warmer temperatures will change species distributions (food web dynamics) as poikilothermic fish and invertebrates attempt to behaviourally thermo-regulate by migrating to cooler water in geographically constrained rivers and lakes. • metabolic rates increase with the consequent need for more food to support this higher metabolism
Run-off changes	• changes in climate over land will cause changes in run-off reaching coastal and marine systems and alter the availability and quality of freshwater – this has implications

	for productivity and ecosystem function of coastal and estuarine environments. • related changes in riverine flooding frequency and intensity will occur.
Ocean stability and currents	• changes to wind and water temperature affect water column stratification and stability leading to changes in upwelling of nutrient rich deeper waters and productivity of surface waters. • Changes to ocean currents, notably the East Australian and Leeuwin currents, may affect dispersal and distribution patterns of marine organisms
ENSO	• some models suggest global warming may lead to an increase in the frequency or intensity of El Nino events – if so, Australia may have more intense droughts and La Nina floods, particularly in the eastern part of the country.
Tropical cyclones and storm surges	• combined with higher sea levels, the projected increase in frequency and intensity of tropical cyclones would cause more frequent and intense coastal flooding. • tropical cyclones may occur further south than they do at present. • there are likely to be shifts in prevailing wind and wave patterns.
Increased fire and wind	• increased frequency and/or intensity of aeolian dust and fire-born particulates can affect coastal productivity and promote blooms.

A global literature review by Hobday *et al.,* (2006) revealed substantial impacts on marine life are already apparent. For example, distributions of fish, plankton, and rocky shore intertidal species are all shifting polewards in the North Atlantic (Beaugrand *et al.*, 2002, Bonnet *et al.,* 2005, Mieszkowska *et al.*, 2005, Perry *et al.,* 2005), while the timing of Antarctic seabird breeding and peak migration dates are also shifting (Barbraud and Weimerskirch, 2006).

Hobday *et al.,* (2006) document that there are relatively few observations of climate change impacts on Australian marine life. However, climate change has been shown to move tropical and temperate phytoplankton southwards off eastern Australia (Blackburn and Cresswell, 1993, Blackburn, 2005). Recent warming of tropical waters has led to repeated mass coral bleaching events on the Great Barrier Reef and elsewhere, a phenomenon not observed globally before 1979 (Hoegh-Guldberg, 1999 and Knowlton, 2001). Declines of giant kelp forest communities in coastal waters of eastern Tasmania have been associated with changing oceanographic conditions including warming temperatures (Edyvane, 2003 and Edgar *et al.,* 2007), and range expansions have been observed in seabird species along the west coast of Australia (Dunlop and Wooller, 1990 and Dunlop, 2001).

Climate change may strongly modify biogenic habitats such as those formed by assemblages including mangroves, tropical corals, kelps, and cold water corals. Further, impacts on dominant producer groups that are sensitive to climate change such as phyto- and zooplankton will have repercussions throughout the aquatic food web. The relatively productive southeastern temperate phytoplankton province is likely to retreat west of Tasmania by the 2070s, with consequent reductions in food web productivity including fisheries yield. Given the projected warming of Tasman

Sea waters and deep waters further south, this area may be particularly sensitive to climate change. Among species most at risk are the coastal species endemic to southeast mainland Australia and southeast Tasmania, noting that the Tasmanian southeast area has the highest localised level of endemism in Tasmania and probably in Australia (Edgar *et al.,* 1997).

Impact on NSW primary industries (Fisheries)

The responsibilities of the NSW Department of Primary Industries under the Fisheries Management Act (FMA) are more than the sustainable management of fishing activity and include conservation of a public resource for the people of NSW. Consequently the impacts of climate change on aquatic ecosystems (natural habitats, protected areas, biodiversity and threatened species) and introduced pests must be considered alongside the effects on wild fish harvest and aquaculture. The latter encompass commercial, recreational and indigenous fishing activities in marine, estuarine and freshwater environments.

1) Aquatic Ecosystems

There were 17 or 19 cycles (dependant on author) in which warmer and colder conditions and associated rise and fall events in sea level have occurred over the 1.8 million years of the Quaternary period incorporating the Pleistocene and Holocene Epochs with significant shifts in species distributions and some extinctions of the terrestrial and aquatic flora and fauna (Frakes *et al.*, 1987, Lambeck *et al.*, 2001 and White, 2006). The impact on the flora and fauna occur when the rate of change due to climate shifts exceed the rate at which the flora and fauna can adapt.

The aquatic flora and fauna in Australia are generally well adapted to short term climate variability but not to longer term rapid shifts in mean climate and increased frequency or intensity of extreme events as predicted under the current climate change scenarios, which incorporate the anthropogenic inputs of greenhouse gasses to the atmosphere (Hennessy *et al.,* 2007).

The impact on NSW aquatic flora and fauna of the predicted changes to the variables in Table 2 will include:-
- An alteration in the nearshore ocean currents with more frequent El Nino Southern Oscillation (ENSO) events.
- An increase in extreme event/storm surges and a decreasing flow of freshwater to estuaries with a shift in nutrient supply to the nearshore coastal waters.

Because the fauna of Australia has a high degree of endemism (greater than 80%) and many species have a restricted geographic range these alterations will be manifest in:-
- significant estuarine and nearshore habitat change;
- change in trophic (food chain) relationships;
- shift in the recruitment patterns of aquatic plants and animals;
- shifts in the range and distribution of species;
- changes in the composition and interactions within aquatic communities;
- and changes in the structure and dynamics of communities.

The primary producers of the aquatic environment are the phytoplankton, which is a key component of ecosystem functioning because phytoplankton control carbon

export by channelling it directly into the food web or through direct sedimentation. The phytoplankton community structure is sensitive to climate change and while no specific studies have been completed in NSW waters, floristic regional shifts have already been reported in relation to mixed layer depth, shoaling and increased stratification in the North Pacific (Karl *et al.*, 2001). Changes in the community structure in response to global warming could therefore profoundly affect the capacity of the aquatic biological community to draw down atmospheric CO_2 and transport it to the deep ocean (Arrigo *et al.*, 1999) or to freshwater river and lake systems.

Impacts on NSW native marine biodiversity and threatened species will be variable and linked to the predicted changes in the principal oceanographic driver on the east coast the East Australian Current (EAC). Possible extension of species range and distribution of warmer water northern species and constriction in the range and distribution of the cooler water southern species is predicted as the EAC and associated anticyclonic warm core eddy systems move south.

The changing freshwater flow to estuaries and the predicted upstream migration of salt water will alter aquatic habitats and change the distribution of plants (wetlands) and aquatic animals (Bunn and Arthington, 2002, Hall and Burnes, 2002 and Schallenberg *et al.,* 2003). Tidal wetlands (particularly saltmarsh Adam, 2002), which are also important nursery habitat, will be reduced in extent because there is rarely the capacity for them to expand landward as sea level rises. In estuaries seagrasses growth rates are temperature and light dependant and redistribution of seagrass habitats will occur as a consequence of the increased temperature and changing light regime (Short and Neckles, 1999).

The scenario for NSW freshwater aquatic systems, is for drying of aquatic areas, increased drought occurrence, higher water temperatures with diminished water flows, which will produce low oxygen levels and increased conductivity (salinity) (Hennessy *et al.,* 2007). Freshwater communities of fish and invertebrates in rivers, swamps and floodplains are likely to experience additional impacts as most species have specialised habitat and dietary requirements (Ficke and Myrick, 2004).

Freshwater flows are a stimulus for breeding in many Australian freshwater fish species (Geddes and Puckeridge, 1989) and thus the changes in volume and timing of spring floods are predicted to significantly impact fish recruitment Burchmore (1990).

With low or reduced flow, freshwater river systems will shift from lotic to lentic environments with a corresponding shift in the biological communities. In shallow freshwater rivers and lakes there is a balance between the phytoplankton communities (heterotrophy) and the bacterial biofilm (mostly autotrophs) on the substrate as the primary producers (Freeman *et al.,* 1994).

Under some climate change scenarios a metabolic shift from heterotrophy (nutritional mode in which absorption of organic matter is required for growth, metabolism and reproduction) to autotrophy (a unique form of metabolism found only in bacteria where inorganic compounds (eg, NH3, NO2-, S2, and Fe2+) are oxidized directly, without using sunlight, to yield energy is predicted.

Compared to the open estuaries and ocean waters freshwater rivers are geographically constrained and limit the migratory options for aquatic plants,

invertebrates and fish. The responses to disturbance are best described in terms of resistance and resilience. Resistance is the capacity of aquatic animals to withstand the forces of disturbance and resilience is the capacity of aquatic animals to recover from the damage incurred through disturbance. For example, freshwater mussels have low resistance and resilience while many algae species have a low resistance but a high resilience.

In NSW the marine and estuarine areas are not as geographically constrained as freshwaters. However, marine protected areas (MPA's) have been established within a framework that considers the comprehensiveness, adequacy and representatives of the delineated geographic area in representing the native habitats and biodiversity. The impact of climate change on marine protected areas was reviewed by Soto (2002) and the key issue was the interconnectedness between habitats. The issue is summarised by the following quote: "the dynamic biogeography brought about by global climate change will effectively alter the 'rules' of ecological conservation" (Soto, 2002). The most likely result of the predicted climate change is that MPA's may not be located in the most appropriate geographic area to represent native biodiversity and habitats.

2) Wild Harvest Fisheries

The aquatic ecosystem changes discussed above will have a direct effect on wild harvest fisheries as the distribution and abundance of aquatic plant and animal species vary in parallel with the habitat changes. In addition recruitment and catch rates in several fish species are associated with seasonal to interannual variability of westerly winds and strong wind events (Thresher *et al.*, 1989, 1992 and Thresher, 1994). A decline in wind due to a poleward shift in climate systems underlies recent stock declines off southeastern Australia and western Tasmania, and these are linked to changes in larval growth rates and recruitment of juveniles in two fish species around Tasmania (Koslow and Thresher, 1999 and Thresher, 2002). Reductions in upwelling of nutrients and extension of warm water along the east Australian coast are likely to reduce prey species abundance, upon which many other species are reliant, including carnivorous fishes, seals and seabirds (CSIRO, 2002).

There are no NSW specific studies on the effects of climate change on the marine and freshwater fisheries, but in 1990 a special issue of the journal Wetlands was published (King and Pollard, 1990) addressing the possible implications of climate change based on the predictions of the CSIRO "Greenhouse 87: Planning for Climate Change" conference (Pearman, 1988). In 1987 the predictions were for a 50% increase in spring summer rain. As this prediction is no longer current some of the impacts hypothesised in 1990 for NSW fishery resources vary with those presented below. However, the document provides a useful (approximate 20 year) historical reference point.

The harvest of Eastern King, school and greasyback prawns will possible decrease as their life cycle relies on the upper estuarine wetland habitat as juveniles, and then they migrate into the offshore prawn fishery in response to the freshwater discharge through the rivers and estuaries. Blue Mackerel a coastal pelagic schooling species of fish, spawn in $17 - 23\,^{0}C$ water in northern NSW and southern Queensland (Ward *et al.,* 2007). This spawning area is predicted to move south with the changes in ocean water temperature and the shift in the behaviour of the EAC.

In freshwater systems water temperature stress will be most marked for stenothermal freshwater invertebrates and fish. This will especially impact the higher altitude and very economically valuable freshwater recreational fisheries, which are based on capture of introduced trout species (Faragher, 1990).

In Australia and NSW, the management of wild harvest fisheries is (or should be) structured within an Ecosystem Based Fisheries Management (EBFM) framework (Scandol *et al.,* 2005, Astles, 2007). As a consequence, risk analysis and adaptive capacity for harvest strategy changes have been incorporated into the Environmental Assessments (EIS) and Fisheries Management Strategies (FMS) for NSW wild harvest fisheries (Astles *et al.,* 2006).

The harvest strategy is based on the variety of fish and invertebrate species which can be taken, the fishing gear/methods able to be used by licensed fishers, the geographic area where fishing by an approved method can occur and the statutory management controls and compliance rules applying to the commercial and recreational fishing industries. The harvest strategies change under the climate change scenarios because of changing recruitment patterns for fish, crustaceans and molluscs, due to changes in physical habitats and the ecological processes in estuaries and the coastal environment.

However, monitoring and predictive modelling of the existing fisheries are necessary to inform the consultative governance and legislative framework for management of the fisheries. If economic viability is reduced as predicted for impacts resulting from climate change, fisheries resource harvest strategies will affect social wellbeing (often negatively). Structural adjustment and adaptive management of fisheries primary industries may be necessary.

3) Aquaculture

In general, temperature increases for NSW, as predicted by the climate change models (Table 2) will benefit the culture of most fish and crustacean species in NSW, especially prawn farming aquaculture in northern parts of the state though trout (culture of that species will be disadvantaged).

However, the area of estuaries suitable for oyster culture is expected to change with rising sea level and salt water intrusion further into estuaries. This may require relocation of shore line infrastructure associated with the oyster industry and pose an increased economic burden. Increasing storm intensity and frequency impacts on estuarine and marine infrastructure for all aquaculture activities may further affect economic return in the industry.

Direct impacts could be expected on the growth rates of bivalves. Elevated atmospheric CO_2, reducing ocean pH will consequently decrease calcium carbonate saturation, threatening calcareous organisms. Gazeau et al., (2007) have shown calcification in mussels and oysters could be reduced by 25 and 10% respectively. Similar findings are now arising specifically with Sydney rock oysters (see Parker et al. in the current investigations section of this paper).

Depending on the magnitude of the change in pH, this could have a very major impact not only on aquaculture but all ecosystems with calcium carbonate based

organisms. Increased acidity is also likely to increase stress in all aquatic organisms, reduce mucus in fish, for example, and make many organisms more susceptible to disease.

The changes to aquatic ecosystems discussed in section (1) above will cause changes in the availability of natural/wild food, which is used in some aquaculture cage pond culture. It will also change the availability of wild caught species used to produce aquaculture feed.

Biofuels and bioenergy are important current areas of research and technology expansion as they provide significant greenhouse gas benefits. The current production base for biofuels uses agricultural feedstocks for both first and second generation biofuels. However, the future production base includes the use of algae as a feedstock in a pyrolysis production process for bio-oils (O'Connell *et al.,* 2007).

Pyrolysis is a system of heating carbon containing materials like algae in the absence of oxygen so that the carbon is not burnt but converted to oil, gas and activated charcoal (char). When using algae as a feedstock research shows pyrolysis at 490^0C is required.

Many algae are currently grown in aquaculture situations as a food for larvae of other aquaculture species or as nutrient sinks in the treatment ponds for the effluent from aquaculture ponds. These algae and specifically grown algal aquaculture crops can be used for biofuel.

Most Australian work on algae for bio-oils is being done in WA and in Victoria. The bio-oil is used in the biofuel production and the gas can be reused to offset the energy needed to produce the temperature for pyrolysis. The char can be used as an agricultural soil improver, where it is stable for thousands of years. It is beneficial as it replaces depleted organic material and increases soil water holding capacity and fertility, reducing the need for fertilizers. The carbon is stored as char and not released as CO_2, so the process removes CO_2 from the atmosphere.

4) Aquatic Pests and Disease

The presence of any given pathogen does not necessarily result in expression of the disease associated with that pathogen. In many cases pathogens can be present without expression of disease – in these cases the host, by various means, is able to defend itself and the pathogen, though present, remains benign. What drives disease outbreaks in aquatic environments is generally poorly understood, however there are three important interactions: factors associated with the pathogen (e.g. virulence, dose, abundance), factors associated with susceptibility of the host (including general health, stress levels, immunity) and environmental factors influencing host/pathogen interactions. Where global warming provides conditions which favour a given pathogen and/or weaken the corresponding host disease outbreaks will occur.

Implicit in the discussion of aquatic ecosystems, wild harvest fisheries, aquaculture and aquatic pests are the changes in optimal habitat and feeding conditions for fish and invertebrates associated with the predicted future climate change, which is likely to lead to stress on the animals. No studies are available for NSW on climate change induced diseases in fish and invertebrates, but there are significant reviews on the

effect of stress increasing disease occurrence in wild and aquaculture fish and invertebrates (Iwama *et al.,* 1997).

Fish are poikilothermic and their metabolic and reproductive physiological processes and disease resistance is temperature dependent. Increased water temperature allows fish to increase their metabolism, which in turn increases their oxygen demand. However the oxygen carrying capacity of warm water is less than cold water. This is especially important in freshwater river systems where temperature stress is likely to be more variable than in coastal systems.

There are variable consequences for exotic/pest species, with a positive impact for some species like the freshwater fish carp where numbers may diminish because of reduced spawning opportunities as floodplains contract. Further increased water temperatures and different water flow regimes may favour expansion of current invaders like *Gambusia* and new invaders like the macrophytes *Eichhornia* and *Lippia.* For other exotics like the marine alga *Caulerpa taxifolia* the distribution may increase because of more suitable conditions in estuaries.

Current DPI initiatives in the fishing industry

Mitigation
Mitigation is about reducing or capturing green house gas emissions and for management of the natural aquatic ecosystems and wild harvest fisheries there are few current activities possible. Exceptions are supporting the reduction in the use of fossil fuels in boats and implementation of low emission technologies for shore processing infrastructure.

Current mitigation research in aquaculture is the DPI collaboration in the NSW algal biofuels project (see appendix).

Adaptation
Current adaptation to climate change for aquatic ecosystems and wild harvest fisheries is by development of the risk management frameworks for fisheries management harvest strategies and incorporation into the Department's governance of the commercial and recreational fisheries (Scandol *et al.,* 2005, Astles *et al.,* 2006, Astles, 2007).

In the aquaculture area investigation of temperature tolerant strains of fish and invertebrates and research into the alternate formulation of aquaculture feeds to reduce reliance on fishmeal provide some adaptation to climate change scenarios.

Gaps/ Opportunities/ Needs
Hennessy *et al.,* (2007) list the Australian and New Zealand national priorities for research in the aquatic field as:-

Natural ecosystems:-
- identification of thresholds including rates at which autonomous adaptation is possible;
- identification of the most vulnerable species (including key potential impacts on key ecosystems;
- interactions with stresses such as invasive species;
- improved bioclimatic modelling; and management options to reduce vulnerability.

Oceans and fisheries:-
- potential impacts of changes in climate,
- ENSO and IPO on physical oceanography,
- marine life and fish stocks in the waters that surround Australia and New Zealand.

Climate surprises:-
- Impacts of abrupt climate change,
- faster than expected sea-level rise,
- sudden changes in ocean circulation.

At the state level research in the fisheries area for NSW Department of Primary Industries to maximise mitigation and adaptation to climate change requires research into sustainable development of marine and freshwater ecosystems, to ensure that they are ecologically healthy as well as economically productive under the predicted impacts. Priorities are:-
- Research into the impact of climate change on ecological health (biological economic and social).
- Research into impacts of sea level rise on estuarine salt marsh, mangrove and seagrass communities.
- Identification of foreshore Crown Land needed as potential buffers to accommodate rise in sea level and as a substrate on which mitigating habitats can develop.
- Robust monitoring systems to understand impacts of climate change especially on recreationally and commercially harvested fish and invertebrates.
- Evaluation of impacts of alternative management and harvest strategies using large scale biogeochemical ecological models.
- Risk based evaluation of proposed adaptation strategies for marine and freshwater fisheries.
- Research into impacts of increasing acidity of the oceans.

Acknowledgments

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Current projects Appendix

A) Sustainable regional development and strategic options for management of marine uses and industries in NSW

A 5-year project in collaboration with CSIRO (commenced in 2005) is undertaking strategic research that will provide the tools and ideas to assist planners, decision-makers and the community to understand how we can sustainably develop our regional coastal and marine ecosystems so that they are ecologically healthy as well as economically productive. This challenge will require an integration of likely climate change scenarios, oceanic and estuarine processes, the complex biology and ecology of natural and man-made systems, economic and social development, and systems of human governance.

The time-span for the modelling work in this project is 1950 to 2030, which captures the historical period of rapid development and environmental change, as well as a manageable projection period of immediate interest to policy matters and aligned with the Australian Greenhouse Office's 2030 predictions of changing rainfall, temperature, sea level rise and oceanic acidity.

The CSIRO's Atlantis modelling framework is being used to evaluate different management strategies designed to address the likely impacts on fisheries resources of different environmental scenarios for an initial study in the Clarence River estuary and for a separate model of the nearshore coastal zone from the Queensland border to the Victorian border. The Atlantis modelling framework is a dynamic, time stepped, biogeochemical model with a coupled physical transport module. Atlantis tracks the nutrient flow through physical, O_2, carbon dioxide, living (multiple) and detrital functional groups in a box model. However due to the computational limitations in Atlantis the nearshore model is based on a large spatial scale of the individual boxes. Preliminary outputs from the estuarine model are expected in 2007. The modelling will then be extended to elsewhere along the NSW coast.

B) Biofuel and Algae Project

This is a three year collaboration between NSW DPI, Newcastle University , Macquarie University and a private company 'The Crucible' that aims to develop a vision, fundamental systems technologies and pathway to implementation that will allow sustainable biocrude production to replace fossil oil as the primary source of transport fuels and industrial materials.

Algal biomass generation and conversion to biocrude represents a production model that does not compete for land area with food crops or regions of high biodiversity. If deployed in regions of low natural primary productivity such as deserts or the open ocean the technique will substantially increase global conversion of sunlight to carbon biomass.

Key technological challenges to the implementation of algal biomass production are the development of scalable algal culture systems that are deployable in identified regions of low natural productivity and the development of techniques that harvest and remove energy from the system but recycle nutrient within the system. Nutrient recycling will be a key technological innovation that will allow culture of algal biomass

to operate as a scaleable closed ecosystem that has inherently sustainable production and minimal impact on surrounding natural ecosystems.

There are four key facets of the research program:

- Development of a systems overview that clearly identifies pathways, hurdles and solutions to social, legal, economic, environmental and technological implementation.
- Evaluation and further development of a low cost, scalable closed photobioreactor/algal culture system for large scale algal biomass generation in regions with minimal current photosynthetic activity (i.e. desert and open ocean).
- Optimisation of pyrolysis conditions for the production of biocrude and char from different algae.
- Tracking the pathway of nutrient from algal culture to pyrolysis products and the development/evaluation of recovery and recycling techniques for system nutrient.

The ultimate aim is to unlock the potential for sustainable (carbon neutral, closed loop) algal biocrude, where the nutrients are recovered and recycled to algae biomass production in a stand-alone cycle or else within the larger agri/aquaculture industry. The output products can then be seamlessly integrated with the enormous capital infrastructure that has developed around existing fossil crude use. Success of the project will elevate biofuels to become a significant and stabilising influence on the global oil market and alleviate concerns associated with large-scale, terrestrial biofuel production.

C) The Effect of Environmental Change on Organisms in Aquatic Habitats

This is a collaborative project between Laura M. Parker (Phd Candidate, UWS), Pauline M. Ross (UWS) and Wayne O'Connor (NSW DPI). Elevated atmospheric Co_2 can cause significant reductions in growth mollusc growth of up to 25% (Gazeau et $al.$, 2007). We have hypothesized that if CO_2 is elevated in the atmosphere there will also be a reduction in the reproductive success and early ontogenetic development of $CaCO_3$ depositors. This could have significant ecological impacts as well as affecting the Sydney rock oyster industry (SRO).

This study will investigate the potential the impact elevated atmospheric CO_2 in combination with the key autecological variables (temperature and salinity) on fertilisation success and growth and survival of SRO embryos, larvae and spat (small juveniles). Preliminary results to date are supportive of the above hypotheses, with a reduction in percentage development, increased deformity and reduced growth of larvae associated with increased atmospheric CO_2.