09 Commercial fishing and aquaculture in northern Australia

Elizabeth Clark, EconSearch esclark@econsearch.com.au
Nick Abel, CSIRO Sustainable Ecosystems nick.abel@csiro.au
Tom Measham, CSIRO Sustainable Ecosystems, tom.measham@csiro.au
Julian Morison, EconSearch jbmorison@econsearch.com.au
Lisa Rippin, EconSearch lmrippin@econsearch.com.au

Trawlers, Karumba
Photo: Larelle McMillan

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1. SUMMARY

1.1 Why is it critical to consider the role of commercial fishing and aquaculture in the development of northern Australia?

Freshwater and marine habitats that support fish resources are under increasing pressure from development, population growth and modification of water catchments around Australia. These pressures are much lower in northern Australia than along Australia's south eastern coasts and fish stocks, as indicated by catch per unit effort, generally appear healthy. However, some fisheries in northern Australia are sensitive to changes in water quality and river flow, and to negative impacts from habitat modification, so damming, water abstraction, weir and road construction and pollution all have a potential to degrade northern Australian fisheries.

1.2 What is the current status?

Coastal, estuarine and inland fishery resources in northern Australia are harvested for human consumption, as a feed for aquaculture and for the ornamental fish trade. The total value of output of the commercial fishing industry in northern Australia is estimated to have been almost $166 million in 2006/07. The industry is reported to generate approximately 370 full-time equivalent (FTE) jobs in the northern Australia region.

The total value of aquaculture production in northern Australia is estimated to have been almost $66 million in 2006/07. Employment in aquaculture production in northern Australia is estimated to have been approximately 411 full time equivalent (FTE) jobs.

1.3 Is this sustainable?

Commonwealth, state and territory management objectives for commercial fisheries are aimed at sustainability, resource sharing and protecting fish habitats. Catch per unit of effort has not been declining in recent years in the major fisheries, and fishing effort is being monitored and regulated, indicating, within the limitations of these measures, that stocks are healthy and governance effective. There is competition between recreational and commercial fishing, particularly barramundi. Land and water resource uses are not currently affecting fisheries at regional scale, but have the potential to do so. Climatic change has the potential to transform water flows and fish habitats, but the magnitudes of changes and their consequences are uncertain.

1.4 What are the likely future trajectories?

There appears to be limited scope for increasing harvests from wild-catch fisheries in northern Australia. Harvests may decline if irrigated agricultural development increases substantially. The rights of Indigenous owners to control access to 5,000km of shoreline in the Northern Territory is a new and unknown factor in the development of commercial (and recreational) fishing. Climate change may derail sustainability and development trajectories.

Aquaculture has significant capacity for growth in both new and existing species and production methods, stimulating job increases and regional economic growth. Its pollution can degrade wild fisheries if not carefully designed and managed. Maintaining environmental standards is crucial. If aquaculture is viewed as unplanned and environmentally damaging, its products may be avoided by consumers. Aquaculture may be a potential resource use for Indigenous communities or individuals. Climate change may also impact on aquaculture development.

1.5 Ways to get sustainable benefits from development of the sector

There are a number of priorities to ensure sustainable benefits are derived from the development of commercial fishing and aquaculture industries in northern Australia:

- Take the potential impacts of climate change, damming, water abstraction and pollution into account in water resource planning under the National Water Initiative
- Monitor freshwater, estuarine and marine fish habitat and quality, and the effectiveness of commercial and recreational fishing gear, as well as catch and effort
- Explore alternative, incentive-based policy measures to promote sustainable commercial and recreational fishing and aquaculture
- Seek alternative aquaculture products and production systems suited to northern Australian systems
- Invest in ecological and policy-related research in proportion to the cultural and economic values of fishing.

These priorities will change if sea level rise removes fish habitats and transforms flow regimes. The rate of change may be much faster than biota can adapt.

1.6 Introductory Overview of Structure and Approach

Commercial fisheries and aquaculture are economically and socially significant to many parts of northern Australia. This chapter aims to provide an overview of commercial fishing and aquaculture in northern Australia as they relate to land and water resource use. Potential industry development options are outlined along with the social, economic and environmental implications of development. Practices, infrastructure, incentives and regulations that can be implemented to maximise the net benefits of industry development are also discussed.

Section 2 provides an overview of the present status of commercial fishing and aquaculture in northern Australia and a brief history of development of the industry. The overview includes an outline of the potential stock and habitat impacts of commercial fishing and aquaculture in the region. Issues relevant to governance of commercial fishing and aquaculture industries and the potential implications for development are also discussed.

Section 3 outlines possible development trajectories for commercial fishing and aquaculture in northern Australia. The socio-economic requirements are described, including:

- capital needs and infrastructure
- skills and labour requirements
- energy supply
- access and exposure to markets, trends and risks.

The socio-economic and biophysical impacts of fishing and aquaculture development are outlined including:

- net economic benefits
- social impacts
- economic and job multipliers.

Section 4 outlines the requirements to maximise the positive impacts of commercial fishing and aquaculture development in northern Australia in terms of:

- practices
- infrastructure
- regulations and incentives.

Section 5 outlines the requirements to minimise the negative impacts of commercial fishing and aquaculture development in northern Australia in terms of:

- practices
- infrastructure
- regulations and incentives.

Section 6 describes the biophysical, economic and social knowledge gaps in addressing the impacts (positive and negative) of commercial fishing and aquaculture development in northern Australia.

2. CURRENT STATUS AND GOVERNANCE

2.1 Commonwealth Fishery Resources

The Australian Fisheries Management Authority (AFMA) is responsible for sustainable management of Commonwealth fish resources. Commonwealth fisheries wholly or partially within the northern Australia region are:

- Northern Prawn fishery
- Torres Strait fisheries
- Coral Sea fishery
- Western Deepwater fishery [1]
- North West Slope fishery
- Eastern and Western Tuna Billfish fishery. [2]

The majority of these fisheries are offshore and unaffected by land based activities. The Northern Prawn and Torres Strait fisheries are, however, potentially influenced by land and water activities and development in northern Australia.

Northern Prawn Fishery

The Northern Prawn fishery (NPF) (Figure 2.1) was established in the late 1960s and is managed by AFMA. The number of vessels operating in the fishery has declined significantly over the last two decades from more than 280 to only 52 as of June 2009 (AFMA 2009).

Catch and value of catch in the fishery over the last five years are detailed in Table 2.1.

Torres Strait Fisheries

The Torres Strait fisheries are managed by the Protected Zone Joint Authority (a joint operation of the Commonwealth Government, the Queensland Government and the Torres Strait Regional Authority). There are ten separate fisheries located within the Torres Strait Protected Zone (TSPZ), for prawns, rock lobsters, Spanish mackerel, pearl shells, dugongs and turtles, barramundi, other finfish, crabs, trochus shells, and sea cucumber (*beche-de-mer*).

The fisheries allow traditional inhabitants to fish for their traditional catch using customary techniques, and recognise the cultures and livelihood needs of the traditional inhabitants.

Catch and value of catch in the Torres Strait fisheries are detailed in Table 2.1

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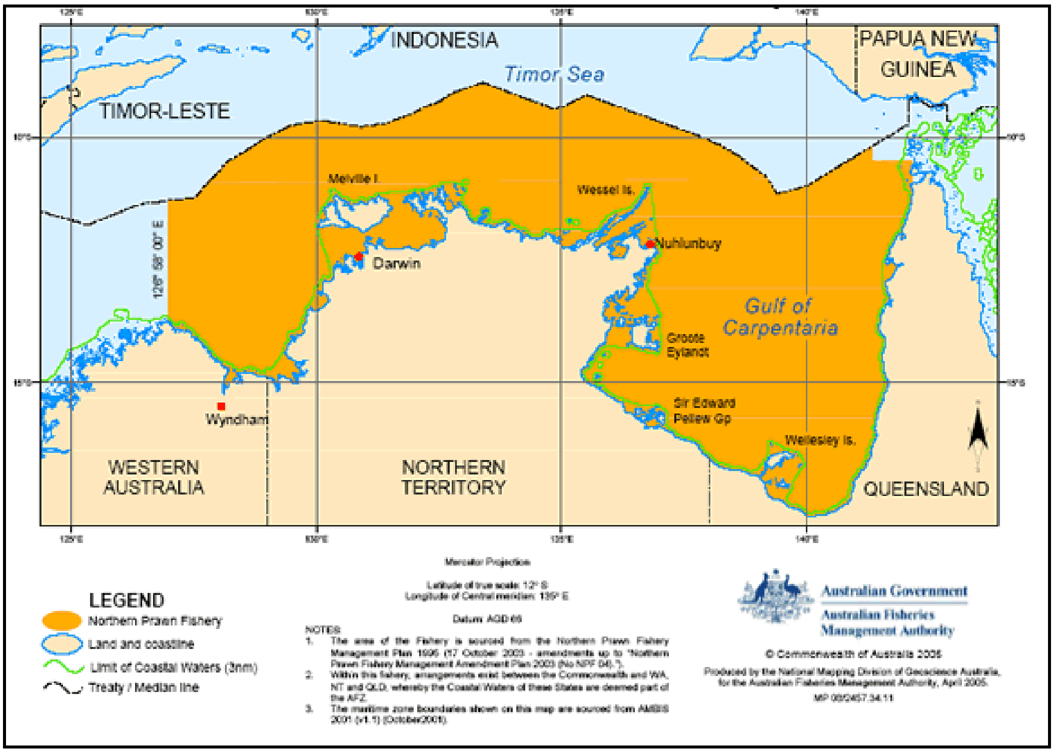
[1] Small area of the most northern part of the fishery is within the boundaries of Northern Australia.
[2] Cover whole of the Australian coast.

Figure 2.1 Northern Prawn fishery boundaries, northern Australia



Source: AFMA (2009)

Table 2.1 Catch and value of catch in northern Australia, Northern Prawn fishery and Torres Strait fisheries, 2003/04 to 2007/08

	2003/04		2004/05		2005/06		2006/07		2007/08	
	Catch (t)	Value ($000)	Catch (t)	Value ($000)	Catch (t)	Value ($000)	Catch (t)	Value ($000)	Catch (t)	Value ($000)
Northern Prawn Fishery										
Prawns	6,192	73,126	5,035	64,263	5,305	72,050	4,893	62,271	6,800	73,352
Other Species	85	854	89	736	95	826	239	1,480	67	771
Total	6,277	73,979	5,124	64,999	5,400	72,877	5,131	63,750	6,867	74,123
Torres Strait Fisheries										
Prawns	1,594	19,787	1,485	15,482	1,342	13,241	1,208	11,674	989	10,445
Tropical Rock Lobster	578	14,311	807	14,399	597	12,258	454	10,423	339	9,428
Spanish Mackeral	199	1,241	154	919	216	1,447	164	1,239	111	676
Reef Line	107	1,327	190	2,186	67	898	83	1,323	39	550
Pearls	0	0	0	0	0	0	0	0	0	0
Other Species	0	0	2	5	9	45	3	12	2	2
Total	2,477	36,666	2,636	32,986	2,223	27,844	1,908	24,659	1,478	21,099

Source: ABARE (2006) and ABARE (2009)

2.2 Western Australian Fishery Resources and Aquaculture

The Western Australian Department of Fisheries is responsible for the management of fisheries along the Western Australian (WA) coast that are within three nautical miles from the shoreline. For the purpose of management and reporting the state is divided into four offshore and two inland bioregions. Inshore fisheries that may be affected by changes in land and water use in northern Australia include:

- Broome Prawn fishery
- Kimberley Prawn fishery
- Kimberley Gillnet and Barramundi fishery.

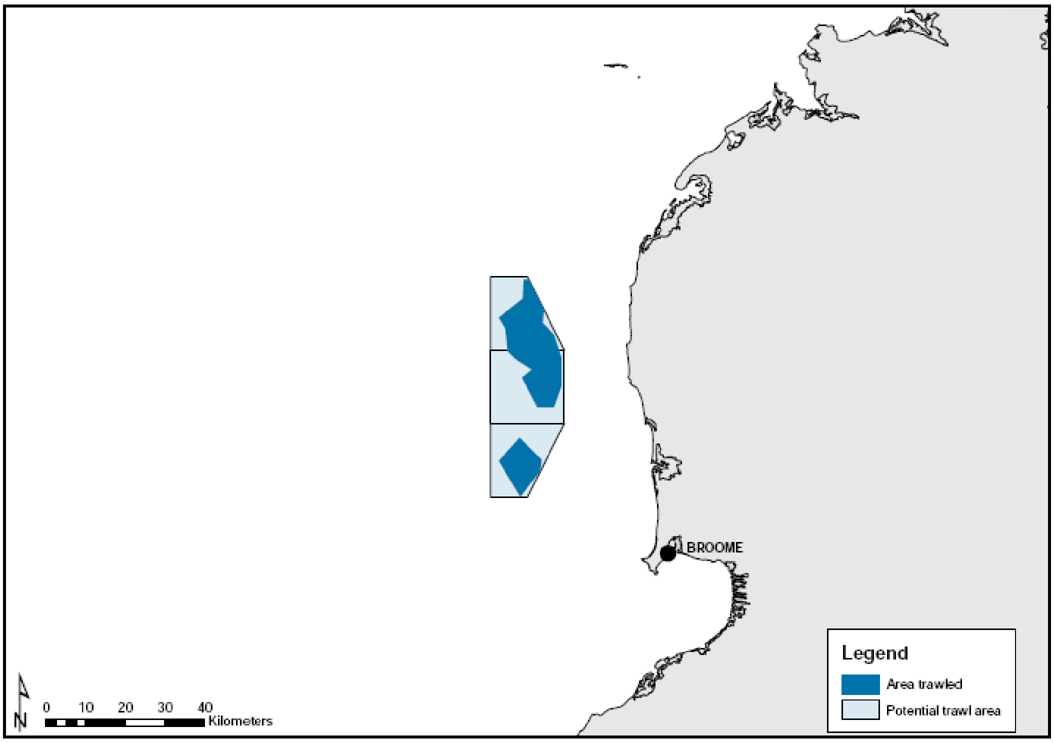
The only significant inland water body that is fished commercially in the northern part of WA is Lake Argyle. The man-made lake was created by the damming of the Ord River. Lake Argyle supports WA's only inland commercial fishery – the Lake Argyle Silver Cobbler Fishery (Fletcher and Santoro 2008).

Aquaculture development in the north of WA includes production of Barramundi in cages in Lake Argyle and production of redclaw crayfish in the Ord river irrigation system (Fletcher and Santoro 2008).

Broome Prawn Fishery

The Broome Prawn fishery operates off Broome (Figure 2.2). Reported catch and value of catch for the period 2002/03 to 2006/07 are detailed in Table 2.2.

Figure 2.2 Broome Prawn fishery boundaries, northern Australia (WA)

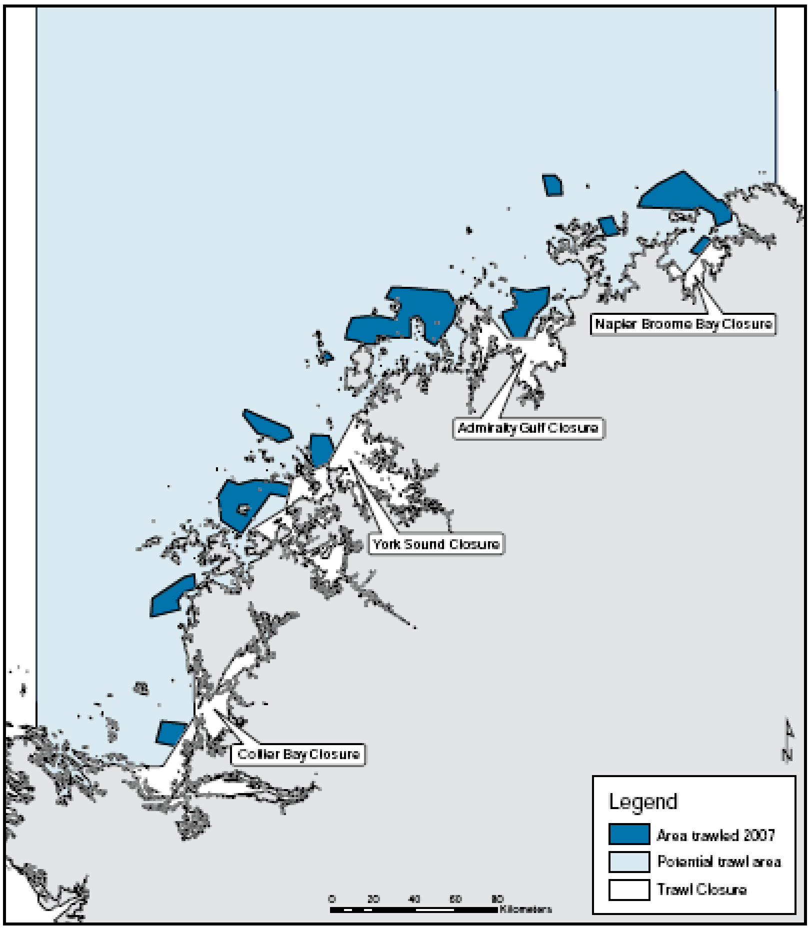


Source: Fletcher and Santoro (2008)

Kimberley Prawn Fishery

Reported catch and value of catch of the Kimberley Prawn fishery for the period 2002/03 to 2006/07 are detailed in Table 2.2.

Figure 2.3 Kimberley Prawn fishery boundaries, northern Australia (WA)

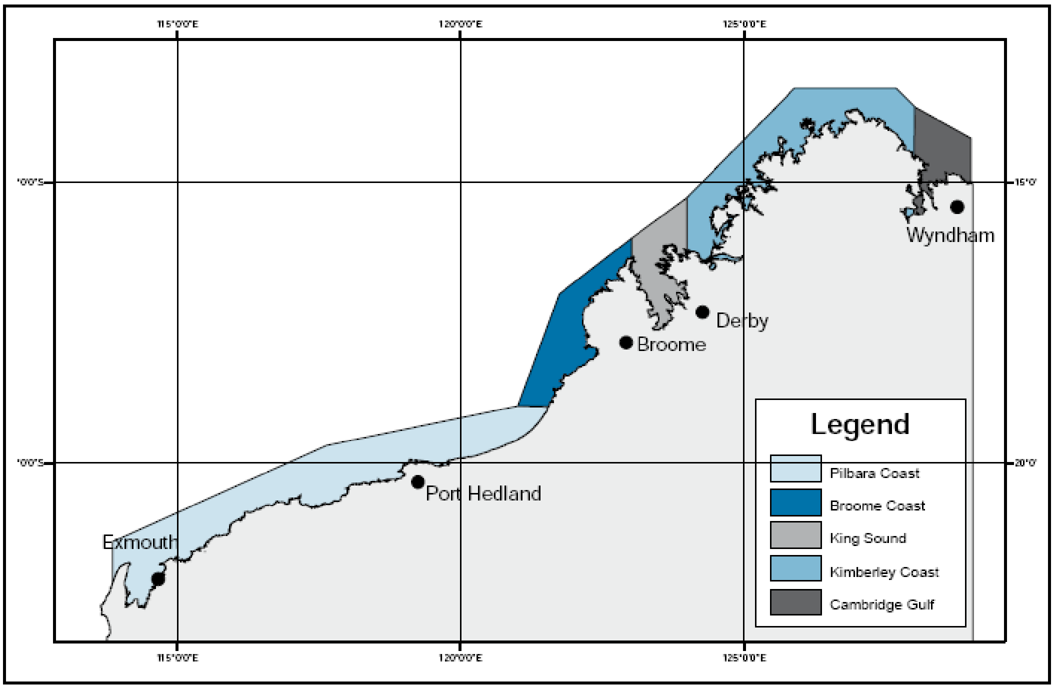


Source: Fletcher and Santoro (2008)

Kimberley Gillnet and Barramundi Fishery

Catch and value of catch in the Kimberley Gillnet and Barramundi fishery are summarised in Table 2.2.

Figure 2.4 Kimberley Gillnet and Barramundi fishery boundaries, northern Australia (WA)



Source: Fletcher and Santoro (2008)

Lake Argyle Silver Cobbler Fishery

The Lake Argyle Silver Cobbler (shovel-nosed catfish) Fishery is limited to six endorsement holders (Fletcher and Santoro 2008). Catch and value of production are in Table 2.2. Estimates of effort and employment in the fishery are also presented.

Recreational Fishing

Lake Argyle and the Ord River support recreational fishing for barramundi and cherabin (freshwater prawns) (Fletcher and Santoro 2008). In 2004/05, approximately 3 per cent of recreational fishers in WA reported that they fished in the fresh waters in the Kimberley. This recreational fishing effort accounts to an estimated 52,000 fishing days (Penn, Fletcher and Head 2005). Water based recreation, including recreational fishing, are discussed in Clark et al. 2009.

Table 2.2 Catch and value of catch in commercial fisheries in northern Australia (WA), 2002/03 to 2006/07

	Year				
	2002/03	2003/04	2004/05	2005/06	2006/07
Broome Prawn Fishery					
Catch (t)	201	124	47	46	72
Value ($m)	1.3	0.9	0.4	0.5	0.5
Effort (nights)	77	77	63	60	39
CPUE (t/night)	2.6	1.6	0.7	0.8	1.8
Employment (no)	20	20	20	16	16
Kimberley Prawn Fishery					
Catch (t)	389	422	265	335	271
Value ($m)	4.3	4.1	2.5	3.1	2.2
Effort (nights)	1,478	1,125	1,051	812	521
CPUE (t/night)	0.3	0.4	0.3	0.4	0.5
Employment (no)	120	120	80	85	80
Kimberley Gillnet & Barramundi Fishery					
Catch (t)	148	136	118	110	109
Value ($'000)	843.0	874.0	713.0	390.0	653.0
Effort (units)	1,377	1,092	882	726	730
CPUE (t/unit)	0.1	0.1	0.1	0.2	0.1
Employment (no)	14	14	14	14	18
Silver Cobbler Fishery					
Catch (t)	165	147	131	78	119
Value ($'000)	440.0	389.0	347.0	207.0	316.0
Effort (net days)	5,070	6,632	6,472	5,279	5,823
CPUE (kg/net day)	32.5	22.2	20.2	14.8	20.4
Employment (no)	12	8	8	6	8

Source: Penn et al. (2005a), Penn et al. (2005b), Fletcher and Head (2006), Fletcher and Santoro (2007) and Fletcher and Santoro (2008)

Barramundi Aquaculture

Production and value of cultured Barramundi in WA are detailed in Table 2.3

Barramundi can be farmed in cages, inland saline ponds or inland recirculated culture systems. In WA the majority of operators produce fish in freshwater cages or intensive recirculating systems (Fletcher and Santoro 2008).

Table 2.3 Production and value of production in WA, Barramundi aquaculture, 2002/03 to 2006/07 [a]

	Year				
	2002/03	2003/04	2004/05	2005/06	2006/07
Production (t)	188	302	289	18	42
Value ($'000)	1,360	1,900	1,300	200	311
Farms (no)	12	17	16	13	n.a.

Source: Penn et al. (2005a), Penn et al. (2005b), Fletcher and Head (2006), Fletcher and Santoro (2007) and Fletcher and Santoro (2008)

2.3 Northern Territory Fishery Resources and Aquaculture

Wild catch fisheries operating in the Northern Territory (NT) are managed by the Northern Territory Department of Regional Development, Primary Industry, Fisheries and Resources. There are 11 wild catch fisheries in the NT:

- Aquarium fishery
- Barramundi fishery
- Coastal Line fishery
- Coastal Net fishery
- Demersal fishery
- Finfish Trawl fishery
- Mud Crab fishery
- Offshore Net and Line fishery
- Spanish Mackerel fishery
- Timor Reef fishery
- Trepang fishery.

The majority of these fisheries operate in coastal offshore waters. However, a number of fisheries rely on freshwater and estuarine environments of northern Australia, including the aquarium fishery, Barramundi fishery and Mud Crab fishery.

In addition to commercial fishing there is also a recreational sector largely based on Barramundi. Water based recreation activities, including recreational fishing, are discussed in Clark et al. 2009.

Aquaculture is also significant in the NT with a number of species being commercially farmed, including

- Barramundi
- Mud Crabs
- Pearl Oysters
- Prawns.

Northern Territory Aquarium Fishery

The NT Aquarium fishery is a multi-species fishery operating in inland, estuarine and marine waters to the outer boundary of the Australian Fishing Zone. The majority of freshwater and estuarine species are collected in waterways close to Darwin and from the Adelaide and Daly River systems (DRDPIFR, 2008). Freshwater species collected include:

- Catfish
- Archerfish
- Glassfish
- Rainbow fish
- Saratoga
- Perch.

Barramundi Fishery

The geographical distribution of commercial effort in the Barramundi fishery has changed significantly of the last 15 years (DRDPIFR, 2008). Effort has moved to more remote areas (such as Arnhem Land) and away from areas where commercial fishing activity is constrained or excluded, including:

- Mary River Fish Management Zone
- Kakadu National Park
- McArthur River
- Adelaide River

Catch, effort, value of catch and employment in the NT Barramundi fishery are detailed in Table 2.4.

Mud Crab Fishery

Mud Crab fishery operations are generally confined to coastal and estuarine areas and are predominantly undertaken on mud flats. The majority of activity in the Mud Crab fishery is concentrated in tidal waters in the Gulf of Carpentaria. Crabbing is also undertaken along the north Arnhem coast, Van Diemen Gulf, Chambers Bay and the west coast down to the Victoria River region. Commercial crab fishing is not permitted in Darwin Harbour, the waterways of the Kakadu National Park, Leaders Creek and a number of waterways adjoining Shaol Bay (DRDPIFR 2008).

Catch, effort and value of catch in the NT Mud Crab fishery are detailed in Table 2.4.

Access to and from the Gulf of Carpentaria, the main crabbing area in the NT, is restricted during wet season flooding. Accordingly effort in the fishery is generally concentrated between May and November (DRDPIFR 2008).

Table 2.4 Catch and value of catch, northern Australia (NT), 2002/03 to 2006/07

	Year				
	2002/03	2003/04	2004/05	2005/06	2006/07
Barramundi Fishery					
Catch (t)	962	1,094	923	981	909
Value ($m)	4.4	5.2	4.6	5.2	5.2
Effort (net days)	30,600	28,190	25,328	27,108	26,870
CPUE (kg/day)	31.4	38.8	36.4	36.2	33.8
Employment (no)	100	100	100	100	100
Mud Crab Fishery					
Catch (t)	393	425	304	266	320
Value ($m)	4.3	6.1	5.4	4.7	6.4
Effort (pot lifts)	950,840	953,664	704,370	680,179	637,863
CPUE (kg/pot lift)	0.4	0.4	0.4	0.4	0.5
Active Licences (no)	49	49	49	49	49

Source: DRDPIFR (2008), DPIFM (2007), DPIFM (2006), DPIFM (2005), DBIRD (2004).

Barramundi Aquaculture

Barramundi aquaculture in the NT began in 1988 with the establishment of a pilot hatchery at the Darwin Aquaculture Centre. A marine sea cage farm was established in 2001 resulting in significant growth in barramundi production. Improved production in marine pond based farms also assisted with production growth (Schipp et al. 2007). The quantity of barramundi produced by the aquaculture sector has fluctuated with some operators converting their barramundi facilities to the production of marine prawns. A recent reduction in prawn prices has reversed this trend (DRDPIFR 2008).

Table 2.5 Production and value of production, NT Barramundi Pond-based Farming, 2002/03 to 2006/07 [a]

	Year				
	2002/03	2003/04	2004/05	2005/06	2006/07
Production (t)	110	116	133	327	385
Value ($'000)	0.9	1.0	1.2	2.8	3.3
Operators (no)	1	1	1	3	3
Employment (no)	4.9	3.4	5.7	12.4	19.5

[a] Estimates are for pond-based aquaculture only (i.e. exclude barramundi produced in sea cages).
Source: DRDPIFR (2008), DPIFM (2007), DPIFM (2006), DPIFM (2005), DBIRD (2004).

The marine sea cage farm ceased operations in 2006, resulting in a decline in barramundi production in the NT. This was partially offset by continued growth in pond based farm production. In 2007 there were three operational barramundi farms that produced marketable fish. All of these farms were located within the Litchfield Shire which is within the boundaries of the northern Australia region (DRDPIFR 2008).

Further expansion and development of the barramundi aquaculture industry will require assessment of new inland or offshore farm sites. If the industry does expand, new development will most likely occur in the Darwin region (DRDPIFR 2008).

Barramundi production by pond based farms in the NT is expected to increase to over 1,000 tonnes by 2009 (DRDPIFR 2008).

Mud Crab Aquaculture

There were three Mud Crab farming operations in the Northern Territory in 2007, one commercial farm and two indigenous pilot projects. Crablets to stock the farms were produced at the Darwin Aquaculture Centre. In 2007 approximately 72,000 crablets were produced and sent to farms. In 2007 employment in Mud Crab farming in the NT was 14.2 full time equivalent employees (DRDPIFR 2008).

Marine Prawn Aquaculture

There was only one prawn farming operating in the NT in 2007. There has been a move away from prawn farming towards other aquaculture species (predominantly Barramundi) as a result of falling prawn prices. Total prawn production in the NT in 2007 was 74 tonnes. The value of this production was $1.2 million (DRDPIFR 2008).

2.4 Queensland Fishery Resources and Aquaculture

Wild catch fisheries operating in Queensland are managed by the Department of Primary Industries and Fisheries. There are 21 commercial fisheries in the state, 18 of which are in the northern Australia region.

Aquaculture is also significant in Queensland, in the northern part of the state in particular. The largest aquaculture sectors in Queensland are land-based prawn and barramundi farms. Aquaculture production in the northern regions of Queensland accounts for a significant proportion of the total value of aquaculture (DEEDI 2009b).

Total aquaculture production in Queensland for the period 2003/04 to 2007/08 is detailed in Table 2.6. Total aquaculture production in northern Australia (QLD) has increased by approximately 14 per cent over the last 5 years.

The gross value of aquaculture production in Queensland for the period 2003/04 to 2007/08 is detailed in Table 2.7.

Table 2.6 Queensland aquaculture production, 2003/04 to 2007/08

	Production (tonnes)				
	2003/04	2004/05	2005/06	2006/07	2007/08
Marine Prawns	3,361	2,964	3,300	3,085	2,943
Barramundi	1,204	1,437	1,745	2,091	2,464
Redclaw Crayfish	91	99	105	100	67
Freshwater Fish	96	105	152	210	196
Other [a]	48	48	25	64	58
Total	4,800	4,653	5,327	5,550	5,728
Northern Australia (QLD)	1,500	1,826	1,772	1,713	1,712

[a] Includes eels, crabs, marine fish and marine hatchery.
Source: DEEDI (2009b) and DPI&F (2006)

Table 2.7 Queensland aquaculture gross value of production, 2003/04 to 2007/08

	Gross Value ($m)				
	2003/04	2004/05	2005/06	2006/07	2007/08
Marine Prawns	53.3	45.9	46.3	42.5	41.5
Barramundi	10.1	11.9	14	18.5	24.3
Redclaw Crayfish	1.3	1.3	1.3	1.4	1.1
Freshwater Fish	0.7	0.9	1.5	2.2	2.3
Hatchery & Aquarium	1.4	1.7	2.1	1.9	1.5
Edible Oysters	0.7	0.7	0.6	0.5	0.6
Pearl Oysters	0.2	0.0	0.0	1.7	1.3
Other [a]	3.6	5.5	4.7	6.8	6.2
Total	71.3	67.9	70.5	75.5	78.8
Northern Australia (QLD)	17.3	22.3	20.2	21.0	20.6

[a] Includes eels, crabs, marine fish and marine hatchery.
Source: DEEDI (2009b)

Mud Crab Fishery

The boundaries of the Queensland Mud Crab fishery are illustrated in Figure 2.5.

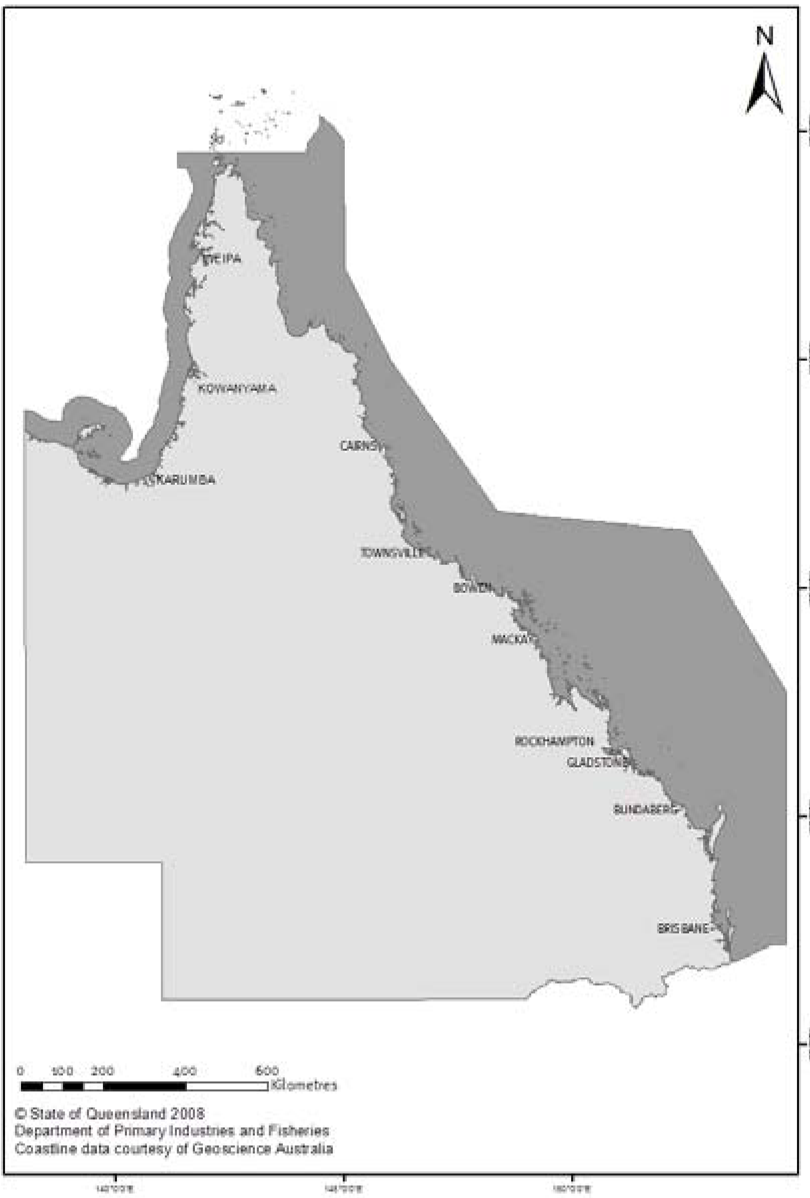
Total catch, effort and value of catch in the Queensland Mud Crab fishery are detailed in Table 2.8.

Total catch in the fishery declined slightly over the period 2003 to 2007. This decline corresponds with a fall in commercial effort in the fishery and number of boats targeting the species. In 2007, total catch in the Carpentaria area of the Mud Crab fishery (from the tip of the Cape to the Northern Territory border) accounted for approximately 14 per cent of total commercial catch (DPI&F 2008).

It is estimated that the commercial sector harvests approximately 58 per cent of total mud crab catch with the recreational sector harvesting the majority of the remainder (41 per cent). Catch by the Indigenous and charter sector is minimal (approximately 1 per cent in total) (DPI&F 2008).

The mud crab fishery was granted a five year Wildlife Trade Operation exemption in 2007. This accreditation acknowledges that the fishery is managed in an ecologically sustainable manner (DPI&F 2008).

Figure 2.5 Queensland Mud Crab fishery boundaries



Source: DPI&F (2008).

Table 2.8 Commercial catch, effort and value of catch in the Queensland Mud Crab fishery, 2003 to 2007

	Catch (t)	Value ($m)	Effort (days)	Number of Boats (no)
2003	1,150	12.1	48,054	502
2004	1,173	12.3	46,557	497
2005	959	10.1	39,878	423
2006	898	9.4	36,099	406
2007	906	14.5	36,737	410

Source: DPI&F (2008)

Marine Prawn Aquaculture

Marine prawn production includes production of black tiger prawns, banana prawns and kuruma prawns. Total production, value of production, area harvested and total number of farms have followed a declining trend in recent years (Table 2.6, Table 2.7 and DEEDI 2009b).

Barramundi Aquaculture

Production of barramundi includes pond-based, cage-based and tank-based systems. Barramundi production has increased in recent years in response to an increase in the number of farms (pond-based systems) (Table 2.6, Table 2.7 and DEEDI 2009b).

Redclaw Aquaculture

Production and value of redclaw crayfish has decreased in recent years. The total number of farms producing this species has also decreased with a number of farms reporting zero production in recent years (Table 2.6, Table 2.7 and DEEDI 2009b).

Freshwater Fish Aquaculture

The freshwater fish growout sector produces silver perch (39 per cent of total freshwater fish production), jade perch (30 per cent) and Murray cod (29 per cent). Small quantities of other species are also produced including golden perch and sleepy cod (Table 2.6, Table 2.7 and DEEDI 2009b).

2.5 Impacts of commercial fishing and aquaculture on stocks and habitats

2.5.1 Commercial fishing

Trawling affects fish habitat through the physical damage it inflicts. By-catch also affects dugongs, dolphins and other non-target species. Examples of the habitat and ecosystem effects of commercial fishing are provided below but these impacts are not considered further in this report.

Ecosystem Effects of Trawling

Assessments of the effects of trawling in the Broome Prawn fishery and Kimberley Prawn fishery indicate that the impacts on the ecosystem, including the sea floor, are minimal. Ongoing monitoring and assessments are undertaken to ensure ecosystem impacts are minimized.

By catch reduction devices are used in both fisheries to minimize the capture of non-target species including turtles and other large animals.

Source: Fletcher and Santoro (2008).

Ecosystem Impact of the NT Mud Crab Fishery

Assessment of the Mud Crab fishery in the NT indicates that the passive fishing methods employed minimise the ecosystem impact. The impact of mud crab fishing on species that feed on the crabs (such as crocodiles, turtles and sharks) is deemed to be insignificant.

Source: DRDPIFR (2008).

Catch per unit effort (CPUE) is an affordable way of estimating fish stocks. Stocks are, however, confounded with the intrinsic catchability of the fish, which can change if fish or boat movement patterns change, and with gear efficiency, which improves over time. Nor is there necessarily a linear relationship between CPUE and stocks (McCluskey and Lewison 2008). We did not assess the information on the sustainability of current catch rates and levels of effort with any rigour, but the CPUE figures that follow give preliminary impressions, subject to the limitations we have noted.

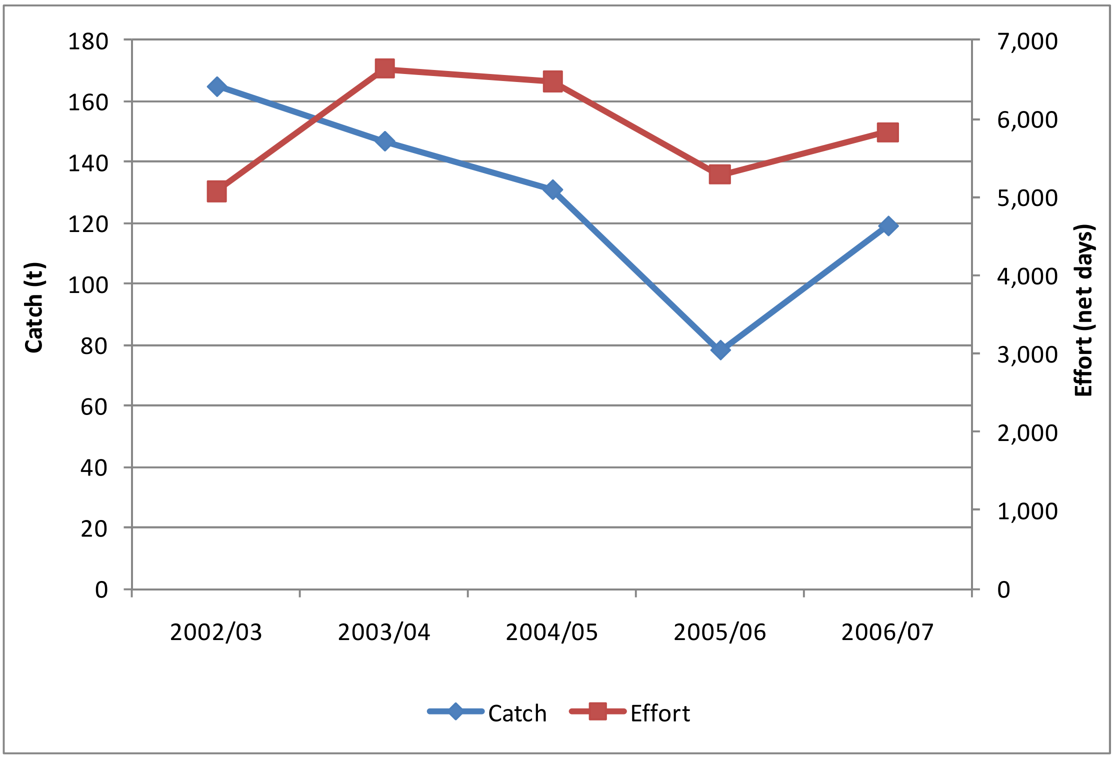
When a new fishery is opened, any fishing effort will reduce stocks, thus, subject to the limitations we have noted, CPUE. In a mature fishery, the main way of managing stocks is regulation of effort. If CPUE is declining, we expect to see a reduction in effort, and an increase in CPUE can be matched by an increase in effort without harming stocks, provided this allows for risks, uncertainties and potential threshold changes. Viewed this way, none of the fisheries in Figures 2.6 to 2.19 appears to be over-fished, though Lake Argyle bears watching.

Lake Argyle Silver Cobbler Fishery Stock Assessment

The catch rate in the fishery increased in 2007 from the low level reported for 2006. The last formal assessment of the fishery, undertaken in 2001, raised concerns regarding sustainability of stock levels. In response to the poor assessment there was a significant reduction in catch. Since then CPUE has fluctuated but generally been higher. There are significant knowledge gaps relating to the target species including growth rates, longevity and mortality.

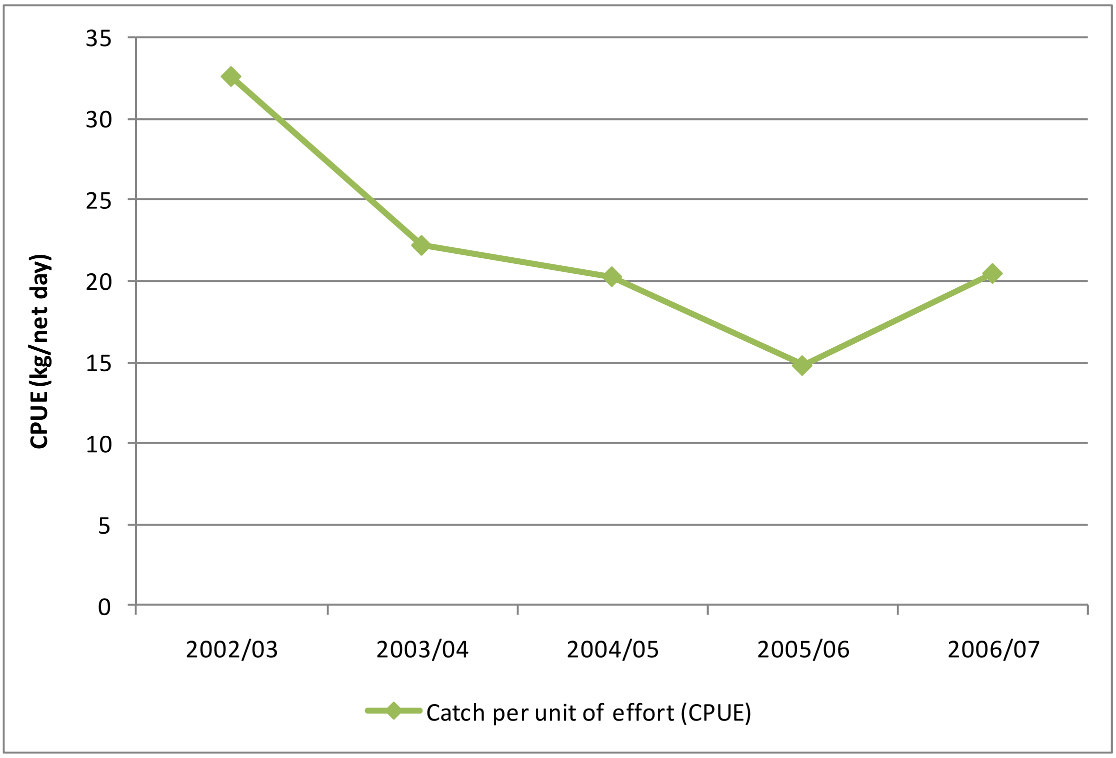
Source: Fletcher and Santoro (2008).

Figure 2.6 Catch and effort, Lake Argyle Silver Cobbler fishery, northern Australia (WA)



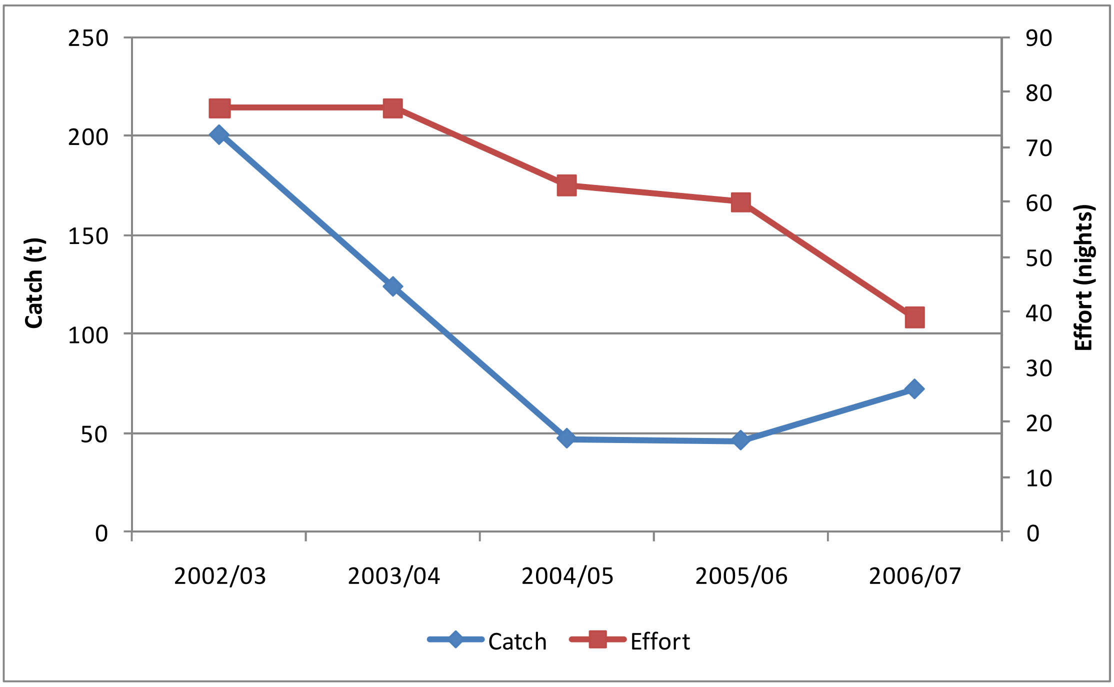
Source: Penn et al. (2005a), Penn et al. (2005b), Fletcher and Head (2006), Fletcher and Santoro (2007) and Fletcher and Santoro (2008)

Figure 2.7 Catch per unit of effort, Lake Argle Silver Cobbler fishery, northern Australia (WA)



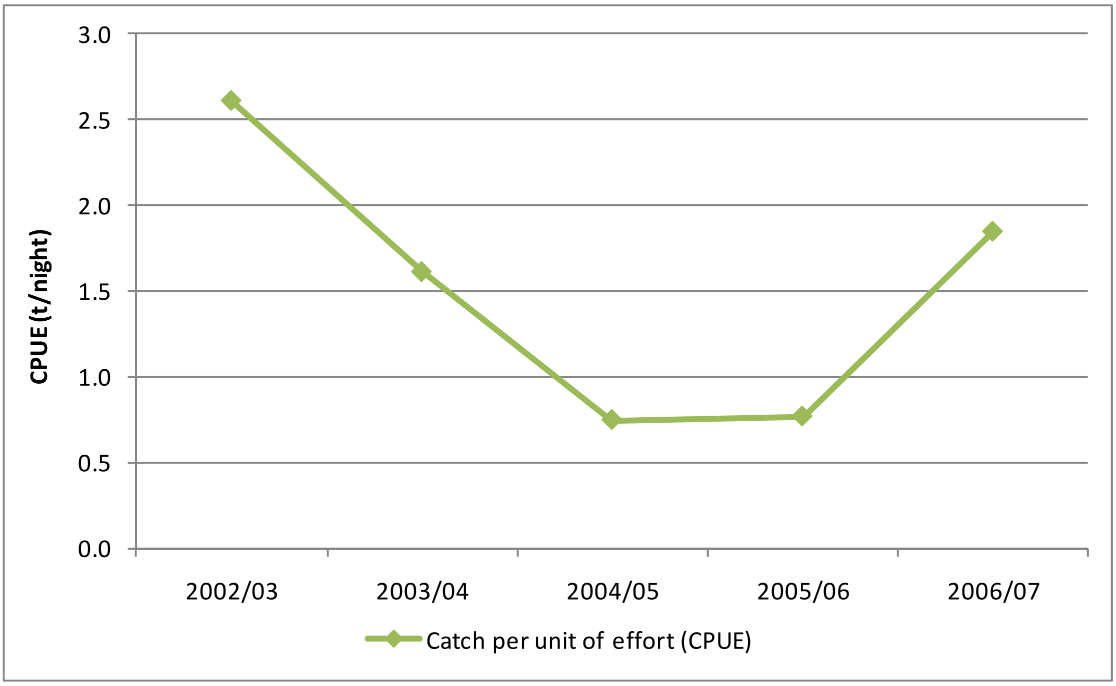
Source: Penn et al. (2005a), Penn et al. (2005b), Fletcher and Head (2006), Fletcher and Santoro (2007) and Fletcher and Santoro (2008)

Figure 2.8 Catch and effort, Broome Prawn fishery, northern Australia (WA)



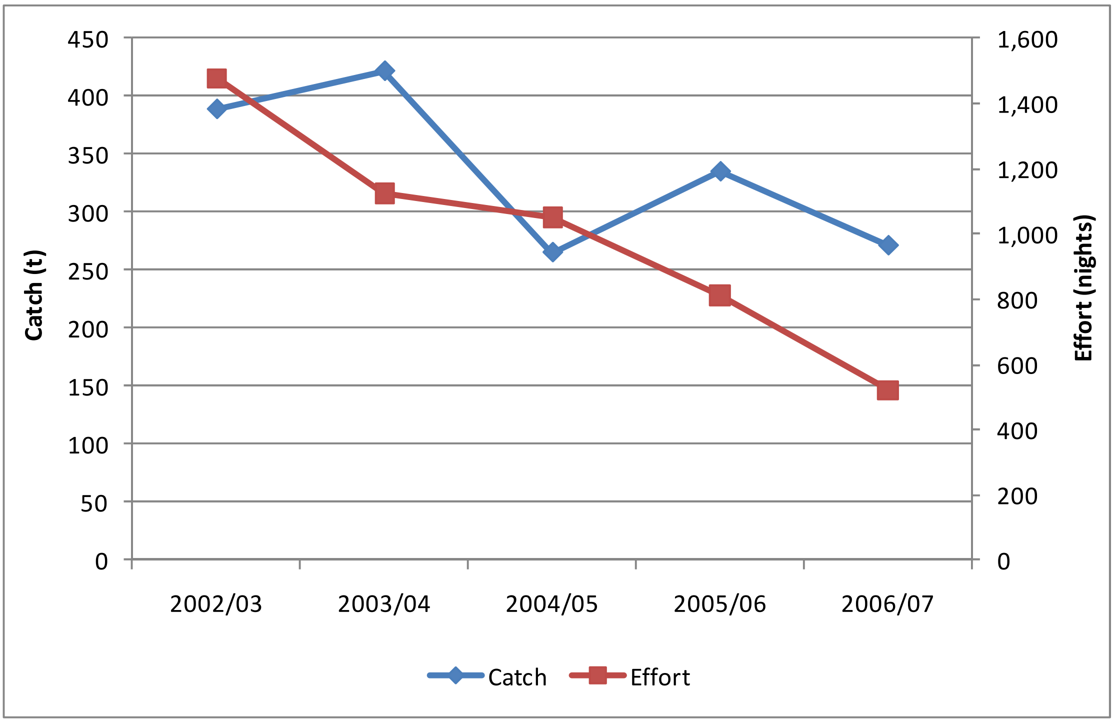
Source: Penn et al. (2005a), Penn et al. (2005b), Fletcher and Head (2006), Fletcher and Santoro (2007) and Fletcher and Santoro (2008)

Figure 2.9 Catch per unit effort, Broome Prawn fishery, northern Australia (WA)



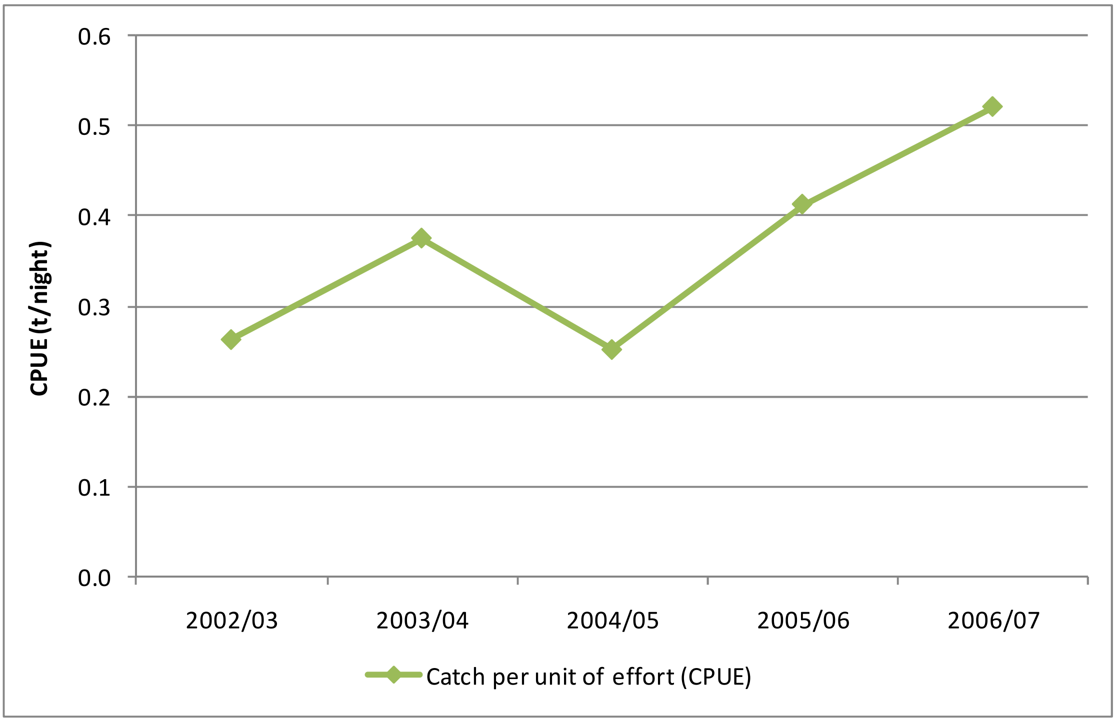
Source: Penn et al. (2005a), Penn et al. (2005b), Fletcher and Head (2006), Fletcher and Santoro (2007) and Fletcher and Santoro (2008)

Figure 2.10 Catch and effort, Kimberley Prawn fishery, northern Australia (WA)



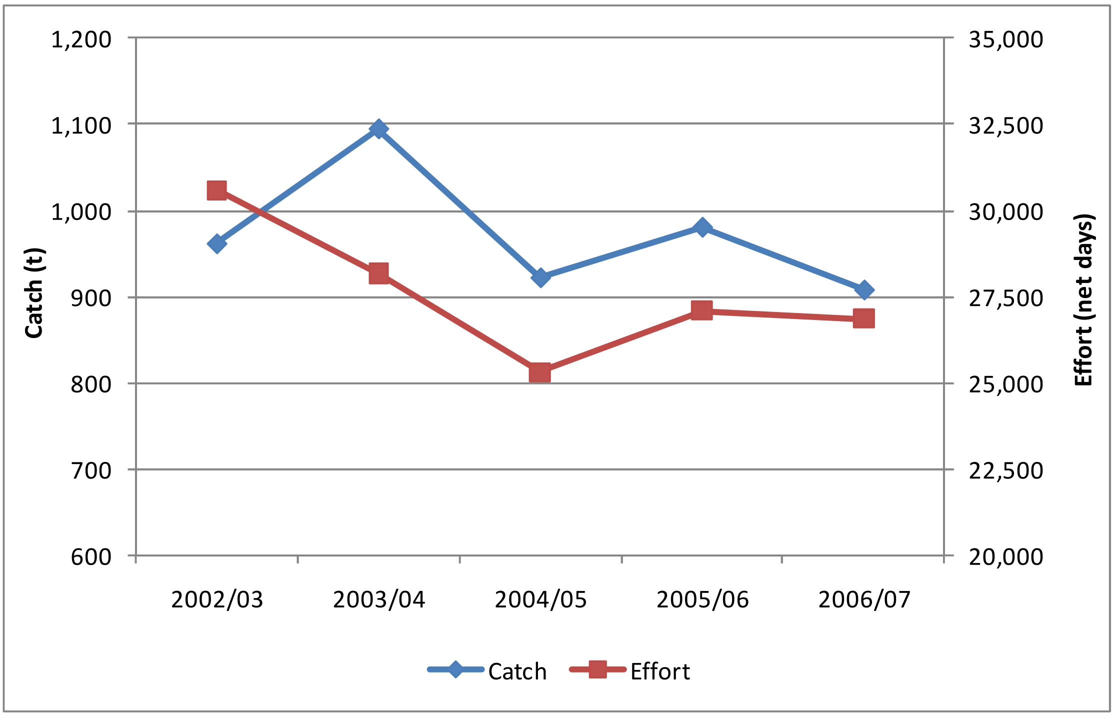
Source: Penn et al. (2005a), Penn et al. (2005b), Fletcher and Head (2006), Fletcher and Santoro (2007) and Fletcher and Santoro (2008)

Figure 2.11 Catch per unit effort, Kimberley Prawn fishery, northern Australia (WA)



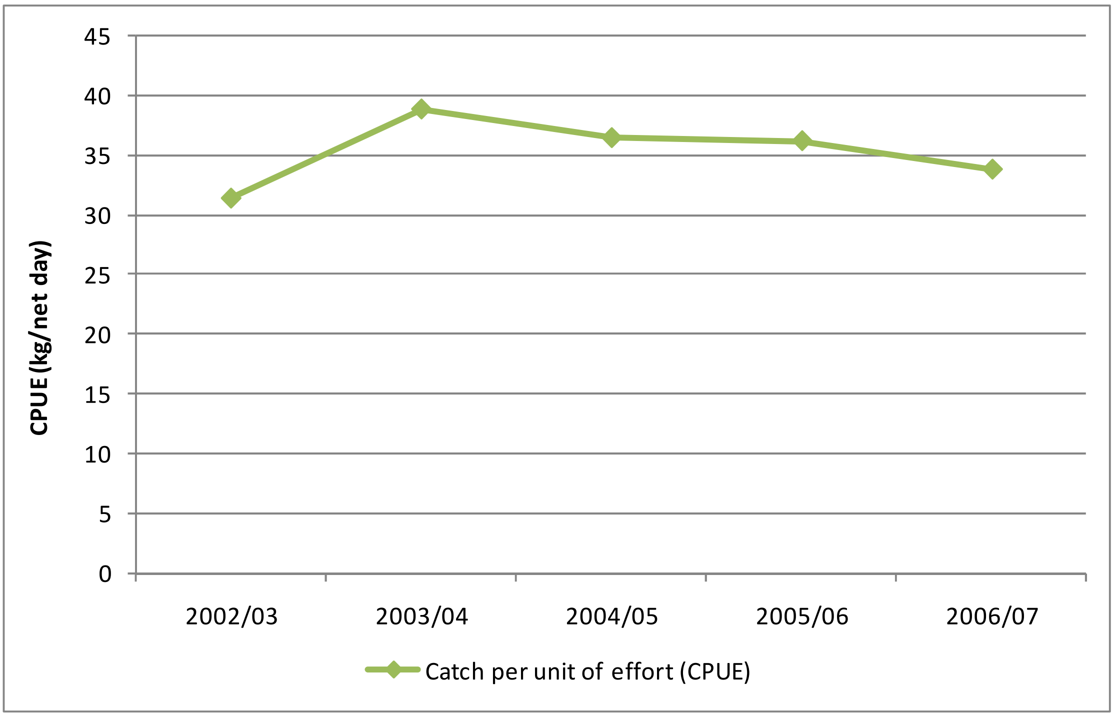
Source: Penn et al. (2005a), Penn et al. (2005b), Fletcher and Head (2006), Fletcher and Santoro (2007) and Fletcher and Santoro (2008)

Figure 2.12 Catch and effort, Barramundi fishery, northern Australia (NT)



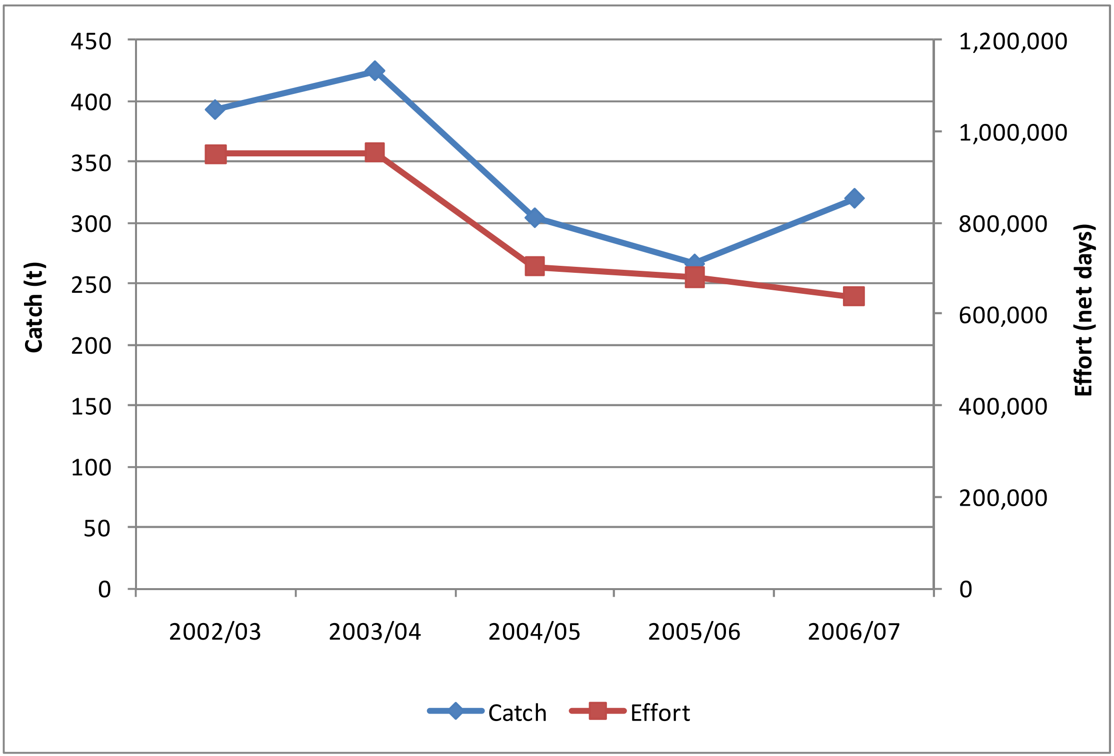
Source: DRDPIFR (2008), DPIFM (2007), DPIFM (2006), DPIFM (2005), DBIRD (2004).

Figure 2.13 Catch per unit effort, Barramundi fishery, northern Australia (NT)



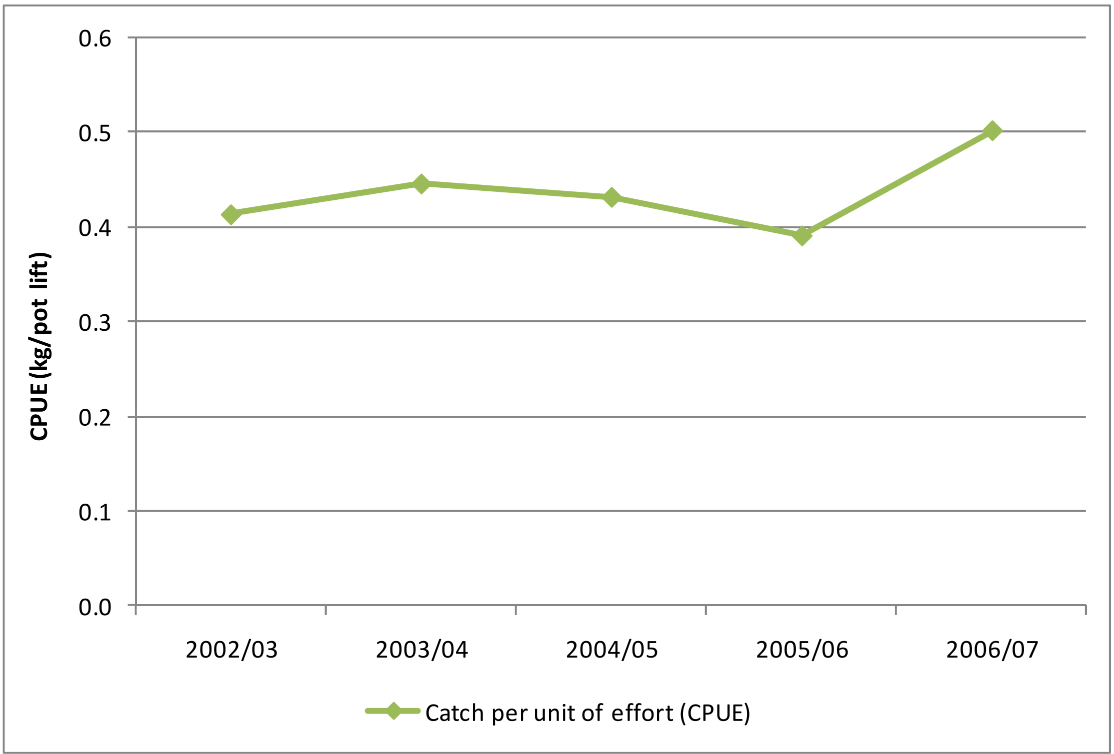
Source: DRDPIFR (2008), DPIFM (2007), DPIFM (2006), DPIFM (2005), DBIRD (2004).

Figure 2.14 Catch and effort, Mud Crab fishery, northern Australia (NT)



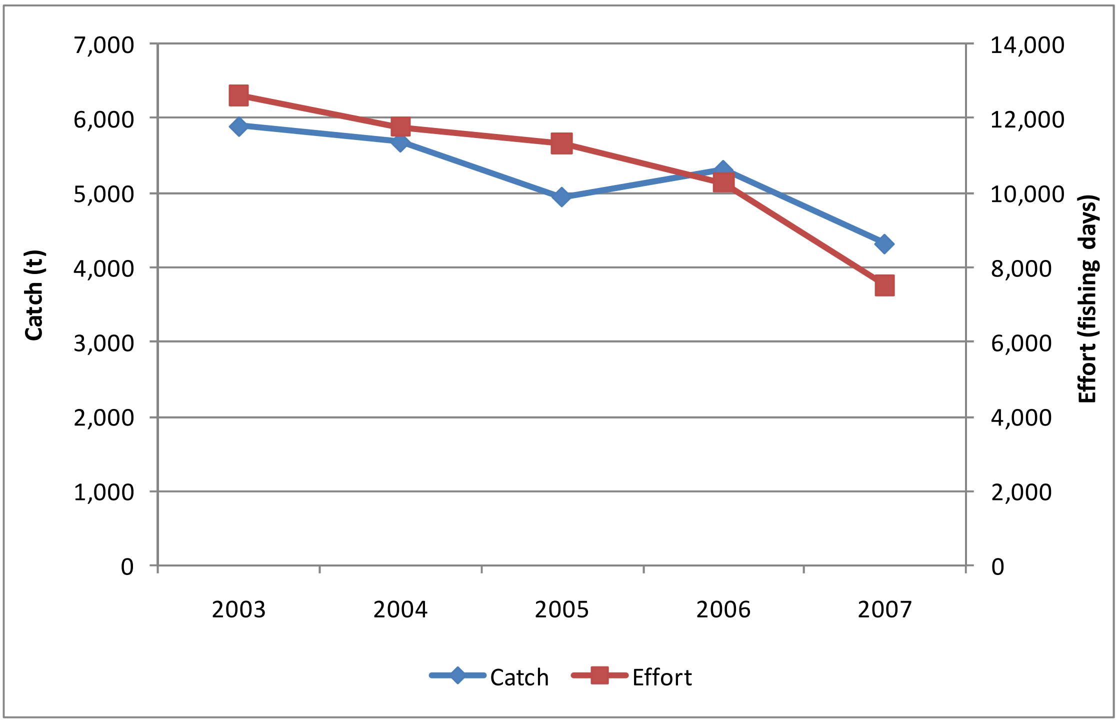
Source: DRDPIFR (2008), DPIFM (2007), DPIFM (2006), DPIFM (2005), DBIRD (2004).

Figure 2.15 Catch per unit effort, Mud Crab fishery, northern Australia (NT)



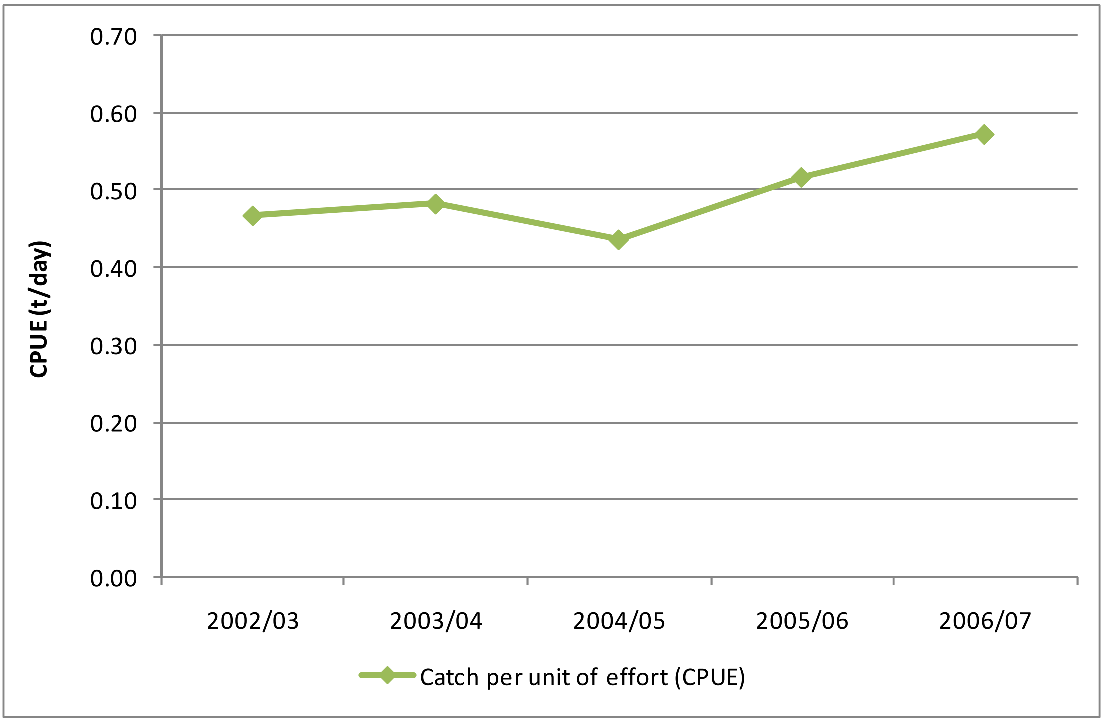
Source: DRDPIFR (2008), DPIFM (2007), DPIFM (2006), DPIFM (2005), DBIRD (2004).

Figure 2.16 Catch and effort, Commonwealth Northern Prawn fishery, northern Australia



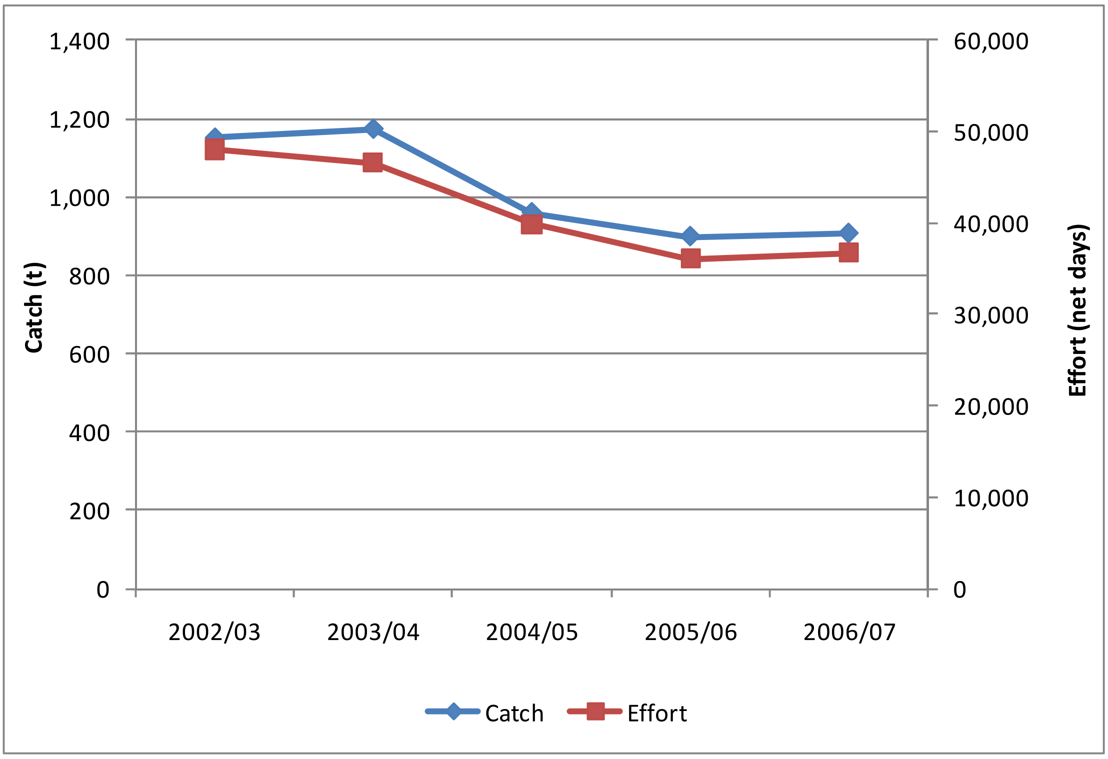
Source: ABARE (2006) and ABARE (2009)

Figure 2.17 Catch per unit effort, Commonwealth Northern Prawn fishery, northern Australia



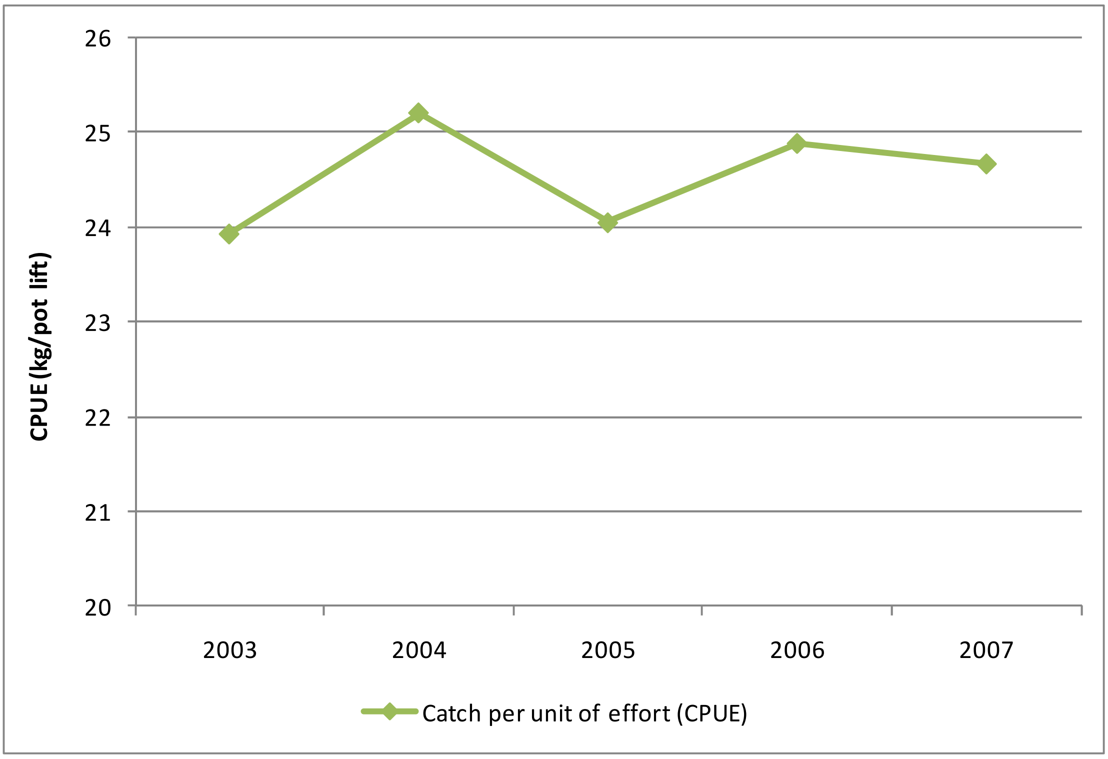
Source: ABARE (2006) and ABARE (2009)

Figure 2.18 Catch and effort, Mud Crab fishery, QLD



Source: DPI&F (2008).

Figure 2.19 Catch per unit effort, Mud Crab fishery, QLD



Source: DPI&F (2008).

2.5.2 Impacts of aquaculture

Aquaculture can have an adverse impact on freshwater, estuarine and marine systems, including:

- nutrient and waste discharge
- fish escapes
- fish meal in feed made from wild stocks
- diseases and parasites
- chemicals, such as fungicides.

2.6 Governance

2.6.1 Commercial Fishing

Fisheries legislation, regulations and policies are intended to maintain stocks by controlling access to fisheries, catch sizes and gear and boat specifications (Table 2.9). Legislation and policies affecting land and water use, including Indigenous property rights, also affect fish stocks and commercial access to them. However, fisheries policies are not linked to policies affecting land and water resource use.

Table 2.9 Commercial fisheries management arrangements, northern Australia

Fishery	Potential for Development Under Current Management Arrangements
Northern Prawn Fishery	The fishery is managed through a combination of input controls including limited entry, seasonal closure, gear restrictions and area closures. The management plan for the fishery provides for the grant of transferable statutory fishing rights that determine the number of trawlers that may operate in the fishery and the amount of gear that can be used.
Torres Strait Fisheries	
Torres Strait Prawn	The fishery is considered to be fully exploited at the present level of effort. Effort within the fishery was capped at 13,400 fishing days 2001 and revised down to 9,200 fishing days for the 2006 season.
Tropical Rock Lobster	Expansion in the fishery is limited to Traditional Inhabitants in order to maximise their opportunities. Boat replacement policy aims to control fishing capacity by preventing the introduction of larger more efficient boats.
Spanish Mackerel	Stock is considered to be fully exploited and likely near maximum sustainable levels.
Broome Prawn Fishery (WA)	Management based on limited entry, seasonal closures and gear restrictions.
Kimberley Prawn Fishery (WA)	Management based on limited entry, seasonal closures and gear restrictions.
Kimberley Gillnet and Barramundi Fishery (WA)	Access to the fishery in the North Coast Bioregion is limited to seven licences.
Lake Argyle Silver Cobbler Fishery (WA)	Fishery is managed through limited entry and gear restrictions. The number of endorsement (licence) holders is limited to six.
Aquarium Fishery (NT)	A moratorium on the issue of any new aquarium licences was implemented in 2001.

Fishery	Potential for Development Under Current Management Arrangements
Barramundi Fishery (NT)	Access to the fishery is limited in terms of total number of licences and total amount of effort. Total effort in the fishery was limited to 19,100 metre net days.
Mud Crab Fishery (NT)	The commercial Mud Crab fishery is restricted to 49 transferable licences with a maximum entitlement of 60 pots per licence.
Mud Crab Fishery (QLD)	A range of input and output controls are in place to manage the harvest of mud crabs. These measures include limited entry to the commercial fishery (limited number of licences/endorsements).

Source: AFMA (2009), PZJA (2007), Fletcher and Santoro (2008) and DRDPIFR (2008).

There is probably limited scope for expanding the numbers of commercial licence holders or quantities of catch in northern Australia.

According to the strategic plan for fisheries in Queensland (DEEDI 2009a) the aim of fisheries management and development in Queensland is to maximise the value of fisheries resources by:

- managing fisheries resources in an ecologically sustainable way
- sharing resources equitably
- facilitating growth of the aquaculture sector
- supporting profitable commercial fisheries
- maximising the recreational fisheries experience
- respecting traditional and customary fishing
- protecting fish habitats.

The strategic plan highlights that aquaculture is the only industry sector with the capacity to increase the quantity of seafood produced in Queensland (DEEDI 2009a). This implies that further development of wild-catch fisheries, in terms of quantity of seafood harvested, is limited.

In the Northern Territory a development permit may be issued to a fisher wanting to harvest a species not already targeted or using different gear. In 2007 development permits were issued for:

- use of crab pots to harvest blue swimmer crabs
- harvest of tropical rock lobster using scuba or hookah gear
- harvest of jellyfish using scoop nets
- harvest of squid and baitfish using a lift net
- harvest of squid and baitfish using a purse seine net
- use of longline and trotline fishing gear in Demersal Fishery.

Fishery development permits and licences are issued to assess a numbers of factors, including:

- ecological sustainability of new commercial fishery activity
- economic feasibility of new commercial fishery activity
- market acceptance and potential.

Only development fisheries that can be shown to be ecologically sustainable can progress towards becoming a commercial fishery (DRDPIFR 2008).

Grants of freehold title to Indigenous people under the *Aboriginal Land Rights (Northern Territory) Act*, 1976 can extend to the low water mark and give traditional owners of coastal land a right to control access. The recent Blue Mud Bay case confirmed Indigenous landowners’ exclusive rights to control access to water above the low water mark. Thus, while the Northern Territory government has the power to grant commercial fishing licences, it does not have the right to allow commercial fishers entry to tidal waters (including tidal rivers) over Indigenous-owned land. It also means that recreational fishers may have to acquire permits from landowners to fish. The decision implicitly acknowledges the adverse impacts of commercial and recreational fishing in the inter-tidal zone on traditional owners' social, cultural and economic interests. It is highly significant in the Northern Territory as it affects more than 5,000 kilometres (or around 85 per cent) of the Territory's coastline (Altman et al., 2009, Chapter 10 in this report – 'Indigenous interests in land and water'). It is not yet known how Indigenous groups will choose to implement these property rights, nor under what conditions they may grant commercial or recreation fishers access.

Access to commercial and recreational fishing and aquaculture sites is limited by Marine Park or reserve legislation in each of the jurisdictions within Northern Australia. A summary of the types of Marine Parks and reserves in WA are in Table 2.10.

Table 2.10 Marine Parks and permitted activities, WA

Category of Reserve	**Level of Activity Permitted**
Marine Nature Reserve	No recreational or commercial fishing, aquaculture or pearling is allowed in these areas.
Marine Park - Recreation Zone	Commercial fishing and aquaculture are not permitted in recreation zones within Marine Parks.
Marine Park – General Use Zone	Commercial activities consistent with the conservation of natural resources are permissible.
Marine Park – Sanctuary Zone	Commercial fishing, aquaculture and pearling are not permitted.
Marine Management Areas	Areas selected and managed based on their biological and recreation values and their existing or future commercial activities (including fishing and aquaculture).

2.6.2 Aquaculture

A review of planning and environmental arrangements for aquaculture in Australia revealed significant differences in the regulation and administration of aquaculture between jurisdictions. These differences have implications for development and management of aquaculture industries (Productivity Commission 2004).

Aquaculture production is subject to a number of legislation and agency conditions relating to:

- marine and coastal management
- environmental management
- land use planning
- land tenure
- native title
- quarantine

- translocation.

Approval for a potential aquaculture development may be required from a number of different government agencies and from local government. The type and extent of approvals is likely to depend on the location, species, type of production system and size of operation (Productivity Commission 2004).

A summary of the regulatory framework for aquaculture production is provided in Figure 2.20.

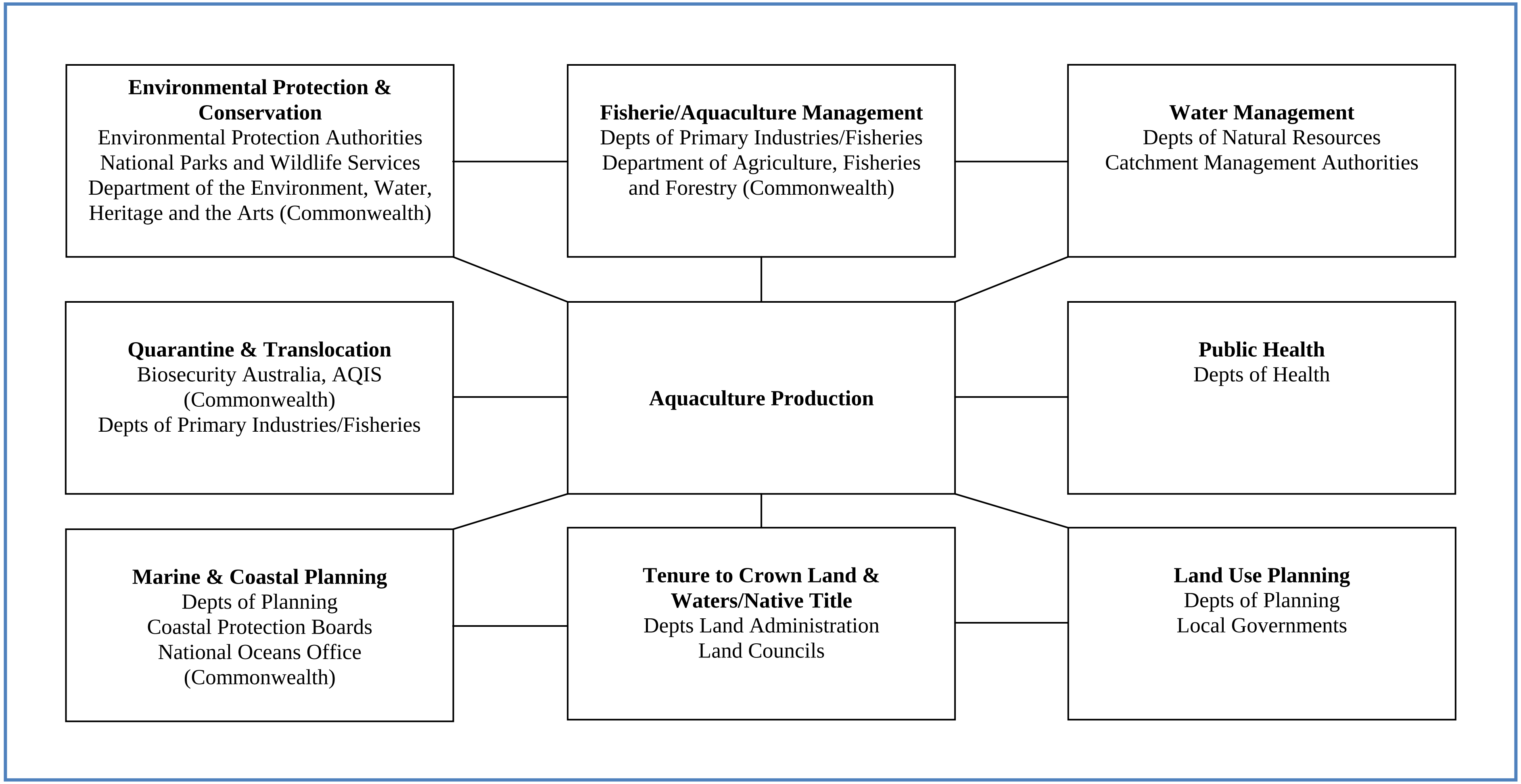
State and territory legislation relating to aquaculture development includes:

- fisheries or aquaculture
- environment protection
- land use planning
- coastal management
- land administration
- water management
- conservation
- native vegetation
- national parks (including marine parks)
- heritage
- native title
- food safety.

Australian Government regulatory involvement in aquaculture production and development includes:

- *Environment Protection and Biodiversity Conservation Act 1999*
- *Native Title Act 1993*
- *Quarantine Act 1908.*

Figure 2.20 Regulatory framework for aquaculture in Australia



Source: Productivity Commission (2004).

3. POSSIBLE DEVELOPMENT TRAJECTORIES

The future development of commercial fisheries and aquaculture in northern Australia depend on these and other factors:

- the viability of fish stocks
- water availability and quality
- climatic change
- commercial access to fisheries, which depends on laws, regulations and policies
- competition with recreational fishing, which has a powerful political lobby
- world prices, which are expected to rise as supplies fall in over-exploited fisheries.

3.1 Potential impacts of water storage, abstraction, pollution and climatic change on development and sustainability

This section draws on Pusey and Kennard, except where references are given.

Freshwater flows to the ocean increase growth rates of fish and prawns, probably because of the nutrients they carry. Faster growth rates lead to better survival of young fish, consequently to bigger catches. Stream flows enable mature fish of species such as barramundi to migrate downstream to spawn in estuaries, and the young fish to migrate upstream where they feed and grow until ready to spawn. These movements are necessary for maintaining stocks, but the fish are also more likely to meet a net or fishing line because they move. Catch per unit effort, a measure of fish stocks plus catchability, generally increases as stream flow increases unless the fishery is being over-harvested. Fished species that depend on freshwater flow include mud crabs, banana, tiger and endeavour prawns, barramundi, king threadfin, grunter, mackerels and sharks. Other species whose abundance depends on freshwater flows are prey for fisheries species, so that reductions in flow can affect fisheries through declines in spawning, recruitment, survival and food supply.

Dams and weirs impact on fisheries by impeding fish movements, and by blocking flows of sediments and nutrients to estuaries. Damming of rivers and abstraction from surface or groundwater can affect the volume of flows, and their duration, frequency, variability and seasonality (Cresswell et al., 2009 - Chapter 1 in this report – Water Resources). The structure, composition and functioning of aquatic systems is strongly determined by these flow attributes, and changes in any of them will result in ecological changes. Mangroves, salt flats, marshes, floodplains and billabongs all require freshwater inputs to maintain them. Abstraction from groundwater can impact directly on wetlands by lowering the water table (Cresswell et al., 2009 - Chapter 1 in this report – Water Resources). All these aquatic systems provide habitat for fish, some of them commercially important. Damming affects volume of flows because it increases evaporation, and water abstracted from a dam may not return to a river. It changes seasonal flow because it stores water during the wet season, when downstream flooding would otherwise occur, and releases it during the dry season when humans need it, causing water to flow through systems adapted to dryness at that season. Dams reduce the frequency of floods by storing any rainfall that would otherwise flow, and they reduce flood variability by storing as much as they can, and release only the amount required by downstream users. Lake Argyle, for example, has a surface area that varies between 1,000km^2 and 2,000 km^2, with proportional evaporative losses. Although a Ramsar listed site, and supporting a commercial fishery, irrigated agriculture and tourism, these need to be offset against the loss of aquatic habits that were inundated, the changes in flow regimes, and the barrier to migrating fish. We do not attempt the comparison in this report.

Agricultural runoff can carry pollutants that potentially harm fisheries (Lovelock and Ellison, 2007). They include pesticides, herbicides and heavy metals. These can affect growth and development of aquatic organisms, dispersion behaviour, reproduction. For example, a single large rainfall event in the Pioneer River catchment in eastern Queensland transported an estimated 470 kg of the herbicide Diuron into the Dumbleton Weir. Residues of other herbicides from cane lands, including amtryn, atrazine, hexazinone and 2,4-D, were also detected. Some of the biocides used in the Darling catchment in the 1970s were still detectable a decade later. Clearing of riparian vegetation and loss of wetlands can reduce their buffering effects and enhance the ability of runoff to transport pollutants (Pusey and Kennard, Chapter 3, Aquatic Systems).

Mosaic development using groundwater to irrigate pasture and fodder for cattle can affect stream flow and fish habitat and food sources through the draw-down of aquifers. In addition, cattle can erode stream banks and affect sediment and nutrient loads, and degrade aquatic systems by trampling.

Although there is substantial uncertainty about climate change, there are likely to be fewer, but more intense rainfall events, thus enhanced runoff from each event and larger floods but of shorter duration, and perhaps less aquifer recharge, which may also lead to reduced stream flows. Larger floods may erode sediments and change channel form. Predicted changes in hydrology are expected to vary greatly across northern Australia. A 2-4 °C rise in air temperature is predicted for tropical regions by 2100. Evaporation rates would increase significantly and this may reduce the persistence of pools in intermittent rivers and wetlands that are important dry season refuges for many aquatic species. Decreased dissolved oxygen concentrations, a function of temperature as well as oxygen availability, may impact on these species. Changes as fundamental as this would cause changes in the species composition and function of aquatic systems that support fisheries.

There is little doubt that sea levels are already rising, but there is uncertainty about the future magnitude of change. The inundation of freshwater wetlands by the sea may occur over a vast spatial scale. If the severity of monsoonal storms increases as expected then the potential area inundated by storm surges is likely to increase accordingly, further impacting on coastal wetlands and floodplains. Such changes would impact greatly on species dependent on those habitats.

Although there is reasonably good understanding about the directions of causal relationships (i.e. +ve or –ve) among freshwater flows, fish habitat, food supply and fish abundance, quantifying the consequences of water development for fisheries is difficult. This is because some of the relationships are lagged (for example changes in erosion-sedimentation regimes that impact on fish habitats), some have thresholds that mark switches to another state (eutrophication, for example) that may not be readily reversible, some impacts are cumulative, and most impacts interact with each other (Carpenter and Biggs 2009). Climatic change adds further uncertainty because its trends, magnitudes and thresholds are not known.

Water quality requirements for aquaculture vary depending on the species cultured. The composition of water in northern Australia can vary significantly both geographically and temporally. Water supplies may require some form of treatment prior to use for fish culture. The type and extent of treatment required is likely to influence the operating costs and overall viability of the aquaculture enterprise. In addition to water quality it is essential to ensure that the quantity of water available is adequate for the proposed aquaculture development. Both can potentially be affected adversely by water storage and abstraction for other uses, and pollution from other uses. Inadequate water quality and quantity can:

- Preclude development of aquaculture operation in a particular area
- Result in sub-optimal growing conditions and growth rates
- Limit the species that can be cultured at the site
- Increase operating costs as a result of water treatment/additives
- Limit the type of operating system that can be used
- Limit the size/production capacity of the development or number of operators.

The effects of climatic change noted above may also affect the quality and quantity of water available to aquaculture, and the location of enterprises as sea level rises.

3.2 Development potential of fisheries and aquaculture

There appears to be little potential for increasing harvests from northern Australian wild fisheries. Most investment should be in managing current stocks well. There are a number of potential aquaculture industry developments across northern Australia. We propose development proceeds under these principles:

- take a precautionary approach
- identify potential thresholds:
    - in drivers (e.g. climate, land use patterns)
    - in key control variables (e.g. aquifer levels, flow regimes, age structure of fish, number of fishers, efficiency of gear)
- identify potential lag effects, cumulative impacts and interactions
- assess risks and their consequences
- acknowledge uncertainties in drivers and in system responses
- promote pilot projects to explore options
- avoid large scale schemes launched ‘courageously’ into an uncertain future.

> *“Investment growth in aquaculture has been restrained recently after rapid growth in the late 1980s and the 1990s. Dominated by prawn and barramundi farming, aquaculture is the only industry sector with the capacity to significantly increase the state’s seafood production. Experience elsewhere indicates that aquaculture is an important development opportunity for many regional centres.”*
>
> Source: DEEDI (2009a).

3.2.1 Queensland aquaculture

Emerging aquaculture sectors in various stages of development in Queensland, include:

- soft-shelled crabs
- mud crabs
- akoya pearl oysters
- sea cucumbers (beche-de-mer)

- tropical marine fish
- Hervey Bay sea scallops
- sponges.

Between 2003/04 and 2007/08 total aquaculture production in northern Australia (QLD) increased by 14 per cent (approximately 3.8 per cent per annum). The value of aquaculture production increased by 3 per cent in real terms over the same period.

Development Trajectory One – Continued Growth in Northern Australia (QLD)

Aquaculture production in northern Australia (QLD) continues to grow at approximately 4 per cent per annum)

3.2.2 Western Australia aquaculture

Tropical Western Australia and in particular the Ord River Irrigation Area of the Kimberley region is considered to have the potential for large scale commercial aquaculture development. Of particular interest to the Department of Fisheries in Western Australia is farmed Redclaw crayfish.

Aquaculture of Redclaw Crayfish

Redclaw is a tropical freshwater crayfish native to the northern areas of Queensland and the Northern Territory. The species is considered to have commercial aquaculture potential in tropical northern areas of WA including the Ord River Irrigation Area.

The development of aquaculture based on an introduced species raises a number of issues, namely:

1. impact on genetic diversity
2. potential for disease introduction
3. impact on the natural environment
4. impact on bio-diversity of native species

Source: DoF (2009).

The Department of Fisheries of Western Australia (DoF 2009) has identified a number of opportunities for aquaculture in the northern area of WA, including:

- *Large prawn farming sites with shallow topsoil above the clay layer, little surface vegetation, negligible pollution, large tidal races for diluting discharge, and proximity to towns with good road access in regions very keen on securing employment options.*
- *Sites that can accommodate about 1,000 hectares of ponds near a significant town, where the water supply doesn't become hyper-saline in the long dry season.*
- *Large tropical coastal sites distant from coral reefs.*
- *High-quality pond sites for cherabin (Macrobrachium rosenbergii) culture.*
- *Indigenous communities having excellent potential aquaculture sites, a large labour pool (many already trained in aquaculture) and an interest in joint ventures with investors.*

- *Large finfish cage sites on the vast Lake Argyle - low cost production because of ideal water temperatures, absence of strong wave action, and no significant predators.*
- *Continued work with salt companies to draw-off hyper-saline water for specialised aquaculture purposes - there are thousands of hectares of salt farms.*
- *Significant areas available in the expanding black pearling farming area.*
- *Opportunities to establish a marine hatchery on the Department of Fisheries' Broome Tropical Aquaculture Park, which offers serviced sites close to a thriving tourist town and assistance with the development of commercial aquaculture technology for several high-value species, such as pearl, trochus, barramundi and prawn.*
- *The coastal and marine environments comprising numerous inlets, mangrove shores, bays and offshore islands. The coast is prone to large tidal variations that, together with summer river discharges, dramatically influence the associated environment.*

Barramundi in Lake Argyle

The Ord River was dammed to create Lake Argyle in support of the Ord River Irrigation Scheme. The lake is the largest man-made lake and irrigation reservoir in Australia.

Since 1994, Barramundi farming has developed into a major industry in the Kimberley region. Lake Argyle Industries has invested in aquaculture infrastructure to increase cage capacity in the lake and other fish management equipment.

Environmental monitoring ensures that the water quality in the lake remains high for the benefit of fish farmers and other users of Lake Argyle.

Source: DoF (2009).

3.2.3 Northern Territory aquaculture

The Northern Territory aquaculture industry experienced a 15 per cent decline in total value of output between 2006 and 2007. This contraction was primarily due to the closure of a sea cage barramundi operation. There is potential to increase land-based production of Barramundi and an alternate operator is being sought for the sea cage operator (DRDPIFR 2008).

Barramundi Farming

Development of the land based barramundi industry will require assessment of proposed sites. Areas within the Darwin region have been identified as the most likely for industry expansion in the short to medium term.

The NT Industry has an aspirational production target of 5,000 tonnes within 10 years. The ability to meet this target is contingent upon the expansion of the pond production sector.

Source: DRDPIFR (2008).

Development Trajectory Two – Growth in Barramundi Production in the NT

Barramundi production in the NT grows from its current level to 5,000 tonnes over the next 10 years.

Commercialisation trials for trepang (sea cucumber) were expected to commence in 2008/09. A pilot hatchery for the species was successfully operated by a private operator within the Darwin Aquaculture Centre (DRDPIFR 2008).

3.3 Requirements for aquaculture development

Table 3.1 summarises the key aquaculture site development factors.

Table 3.1 Aquaculture site development in northern Australia, factors to consider

Factor	Description
Land Tenure and Native Title	Access to water, road access and impacts on places of heritage.
Previous land use	Chemical residues in soils (e.g. pesticides) may affect production, saleability and safety of the aquaculture product.
Surrounding land use	Urban and agricultural activities have the potential to conflict with aquaculture production.
Predators	Birds and other predatory animals in the area.
Road access	All weather road access for supply of goods and services.
Electricity	Access to three-phase power.
Market access for products	Access to domestic/international transport routes.

Source: DEEDI (2009c)

Aquaculture enterprise profitability can be affected by:
- Water quality, volume and reliability
- Climate
- Remoteness (transport costs, cost of attracting skilled labour)
- Laws and regulations
- Capital and operating costs
- Market
- Development costs of unproven production systems

3.3.1 Capital needs, infrastructure

Aquaculture is capital intensive and, depending on the lifecycle of the species cultured, it can take a number of years before a positive return is achieved.

Investment

The ability to attract investment has the potential to act as a constraint to aquaculture industry growth. Potential for variation in environmental and climatic conditions can add additional risk to investment in aquaculture development.

Source: Productivity Commission (2004).

Aquaculture sites should have access to mains electricity (three phase), roads and be within reach of an urban area so staff have access to accommodation, shops and recreation. If aquaculture enterprises should be located close to hatcheries to minimise travelling time between each. In the case of prawns for example, the travelling time should be less than 12 hours and preferably less than three hours, including air freight and/or road travel.

The development site should have access to an estuary or marine supply with an optimum salinity range suitable for the species. The seasonal effects of rainfall and evaporation can cause fluctuations in salinity. Water sources can also be affected by pollutants from industrial activities, urban development, agriculture and water treatment facilities. Tidal movements in estuaries need to be considered to ensure that adequate quantities of water are available.

A land based aquaculture operation may require access to public land. This may be for the aquaculture facility itself, for access to water supply/discharge point or to access other infrastructure (e.g. transport, power) (Productivity Commission 2004).

Public land and aquaculture in Western Australia

"In Western Australia, for example, around 36 per cent of the state is 'unallocated Crown land', 38 per cent is pastoral lease, and 19 per cent is reserves and other leases. It is considered that the majority of the land sites suitable for major aquaculture developments in the state (for example, prawn farming, abalone or microalgae) are on non-freehold sites. In addition, in Western Australia, all near coastal freehold sites require access by way of easement to the ocean (Lendich 2003). Aquaculture on any of these sites would require a public lease and, where applicable, would need to be consistent with native title."

Source: Productivity Commission (2004).

3.3.2 Skills, labour

As the complexity of the aquaculture production system increases the skill level and specialisation of workers required increases.

Aquaculture development is likely to require employment and training of both skilled and unskilled labour. Where the specific marine industry and aquaculture skills required of employees are lacking in a region there will be a need for skills development.

In regional areas, such as a number of locations in Northern Australia, it is unlikely that appropriately skilled staff or technical expertise will be available. It can be difficult to attract staff to work and live in remote areas. This can escalate the cost of labour.

3.3.3 Energy supply

Many potential development sites in Northern Australia are likely to be in remote locations. The location of the development may determine the type of culture system that can be operated. Intensive production systems rely heavily on power for pumps and aerators.

Lack of or a limited power supply has the potential to restrict the type and size of the aquaculture facility including cool room and processing capacity.

The cost of accessing a power supply needs to be considered. The cost of laying power lines is high and likely to be prohibitive for a small operation. Laying power lines could involve costly cultural heritage surveys in culturally sensitive areas.

> Artificial aeration is an effective way of preventing stock mortality during periods of low dissolved oxygen. Accordingly, access to mains electrical power (preferably three-phase) is essential for any pond or tank-based aquaculture development (DoF 2000).
>
> Source: DoF (2000).

3.3.4 Access and exposure to markets, trends and risks

The location of the aquaculture development has the potential to influence access and exposure to markets for cultured products. Developments in remote locations are likely to incur higher delivery costs than competitors located closer to major towns and cities.

Australia has established itself in a few international seafood markets namely, tuna, rock lobster and abalone. The quantity and value of Australia’s seafood exports is insignificant by international standards. There may be potential for expansion in the quantity and value of Australian seafood exports in response to growth in markets in China and other Asian countries (DEEDI 2009a).

There is also potential to expand exports into Europe and the United States. In the US and a number of European countries successful campaigns undertaken by non-government organisations have forced retailers to source seafood products from sustainable sources (DEEDI 2009a). This presents an opportunity for sustainable wild catch fisheries and aquaculture industries in Northern Australia.

Mud Crabs

Mud crabs are a premium seafood product. There is strong demand for live mud crabs from domestic markets including Melbourne and Sydney. In the past mud crabs have also been exported from the Northern Territory to markets in China, Singapore and the United States (DRDPIFR 2008).

Mud crabs caught in Queensland are sold in local and domestic markets. Availability of mud crabs is important to the tourist and hospitality trade for their iconic value. There is some live export of mud crabs to Asian markets (DPI&F 2008a).

Barramundi

Barramundi produced in the Northern Territory (aquaculture product) is currently primarily sold to interstate markets (95% whole fish over 1kg and 5% plate size less than 1kg) (DRDPIFR 2008)

Barramundi produced in Queensland aquaculture systems are sold on the domestic market. Product is sold through agents, wholesalers, fish markets such as the Sydney Fish Market and directly to supermarkets and retailers. Sale of fillets makes up the majority of sales (approximately 70 per cent) with the remainder of sales being primarily whole 'plate size' fish. Small quantities of live barramundi are sold to specialist restaurants (DPI&F 2008b).

Barramundi prices have dropped as domestic supplies have increased. Increasing imports from Asia also place downward pressure on prices. The price of Barramundi is expected to continue to fall (Seafood Farming Services, 2004).

Prawns

Increasing quantities of prawn imports has placed downward pressure on domestic product. There can be large seasonal price fluctuations reflecting availability of wild and farmed product (Seafood Farming Services, 2004).

Market Development and Access

Community perspectives of aquaculture and export markets have the potential to affect industry development. Large retailers are moving towards buying products from producers with genuine environmental stewardship. If aquaculture is viewed as unplanned and environmentally damaging it may be ignored or avoided by these retailers. Access to export markets is improving although trade barriers have an adverse impact of market accessibility.

Source: Productivity Commission (2004).

3.4 Social and economic impacts of development

3.4.1 Economic benefits

Potential economic benefits and costs of aquaculture development are summarised in Table 3.2.

Table 3.2 Economic benefits and costs of aquaculture development

Potential benefits	**Potential costs**
Increased income for those employed in aquaculture enterprise.	Potential loss of amenity value at aquaculture development sites borne by residents and visitors.
Increased income for employees and businesses in support services and industries that grow as a result of aquaculture development.	Economic cost of potential adverse ecosystem impacts (e.g. disease outbreak, waste discharge, etc.).
Reduced costs for residents and businesses using improved transport and infrastructure networks.	
Residents and businesses benefit from regional economic development resulting in improved and expanded services and facilities.	
Existing aquaculture operators benefit from increased research and development potentially resulting in productivity improvements.	

Net economic benefit (benefits less costs) is a measure of economic efficiency. It is not the same as economic impact, which is about changes in the size of the regional economy, the structure of its sectors, or changes in employment. An investment with large impacts is not necessarily an efficient one, but benefit-cost analysis can only be applied to defined projects, which is outside the scope of this report. Impacts are addressed below (Section 3.4.3), using data derived from input-output models.

Many small regional communities are characterised by heavy reliance on one or a small number of major industries, combined with basic services. They lack the diversity of larger economies and their multiplier effects on regional output and jobs.

If expansion of the aquaculture industry in northern Australia did occur and the industry became stable and sustainable further economic impacts could be generated by investment of profits in new or under resourced local ventures by aquaculture operators. These impacts would be in addition to regional impacts generated by recurrent expenditures in the aquaculture sectors.

The aquaculture sector is characterised by a high level of innovation. An expansion of the aquaculture sector in northern Australia may present opportunities for additional education and research in the region.

3.4.2 Social impacts

The social impacts of commercial fishing are likely to be upon Indigenous and recreational users and the tourism industry (Altman et al., 2009, and Clark 2009). It is caused by competition for fish, although there is evidence that for significant numbers of anglers it is the enjoyment of fishing that anglers value, not the number of fish caught (Rolfe and Prayaga 2007). A national survey of recreational fishers identified, in descending order of importance, ‘to relax and unwind’, ‘fishing for sport’, ‘to be with family’ and ‘to be outdoors’ as their main aims (Henry and Lyle 2003). Only a small proportion rated catching fish for food as their primary goal.

Knowledge on the social impacts of aquaculture is limited by lack of research nationally and internationally (Mazur and Curtis 2006). In southern Australia residents value the economic and employment potential of aquaculture, particularly as an avenue for youth employment in remote coastal regions. However the perceived benefits from aquaculture in Australia are not well understood, and levels of support by residents mostly unknown (Mazur and Curits 2006).

The potential for inequitable distribution of costs and benefits from aquaculture is recognised, and has been observed in Mexico where pro-aquaculture policies have displaced local fishermen (FAO 2006; Perez-Sanchez and Muir 2003). Regional employment can decline when local fishing grounds are converted into ponds for aquaculture, for example when multi-use, common property wetlands such as mangroves are converted into private ponds (Bergquist 2007).

From a northern Australian perspective there is a concern that the benefits from aquaculture and commercial fisheries are mostly exported. There are a few exceptions - small projects with local Indigenous communities developing new skills while remaining on country. However, these initiatives have limited commercial viability. That would require lower labour costs and export of products to secure a good price (Greiner et al 2006). Nevertheless, aquaculture has been identified as a potential contributor to Indigenous development in the National Indigenous Aquaculture Development Strategy (Lee and Nel 2001 p 57) where it is proposed as a means to:

- enhance pride and economic control
- build stronger relationships between communities
- provide a goal for younger people.

Aquaculture that benefits local Indigenous communities is characterised by (Lee and Nel 2001) as having:

- local ownership
- strong communication with community members and their council, traditional owners and other affected parties
- non-Indigenous partners trained in protocols for doing business with Indigenous communities.

3.4.3 Economic and job multipliers

A multiplier is an index (ratio) indicating the overall change in the level of activity that results from an initial change in economic activity. Input-output (I-O) multipliers are an indication of the strength of the linkages between a particular sector and the rest of the regional economy. As well, they can be used to estimate the impact of a change in that particular sector on the rest of the economy.

A multiplier is a measurement of the impact of an economic stimulus. The stimulus we apply is normally an increase in final demand by a specific sector, which causes that sector to grow and influence growth in other sectors. The impact of the stimulus can be measured using a number of indicators including a change in gross regional product and employment in the whole regional economy.

The economic impact of commercial fishing and aquaculture are generated through the demand for local goods and services. An increase in fishing or aquaculture activity results in an increase in demand for material inputs and employment of labour.

Expenditure by commercial fishing and aquaculture sectors in northern Australia is concentrated in a number of supply and service industries, including:

- wholesale trade
- retail trade
- metals and metal products
- road transport
- property and business services.

A change in activity in fishing and aquaculture in northern Australia has implications for sectors with strong linkages, such as those listed above.

Estimates of economic and population impact were calculated for development trajectories for commercial fishing and aquaculture in northern Australia. The trajectories used as a basis for the analysis are detailed in Table 3.3.

Table 3.3 Development trajectories, commercial fishing and aquaculture, northern Australia

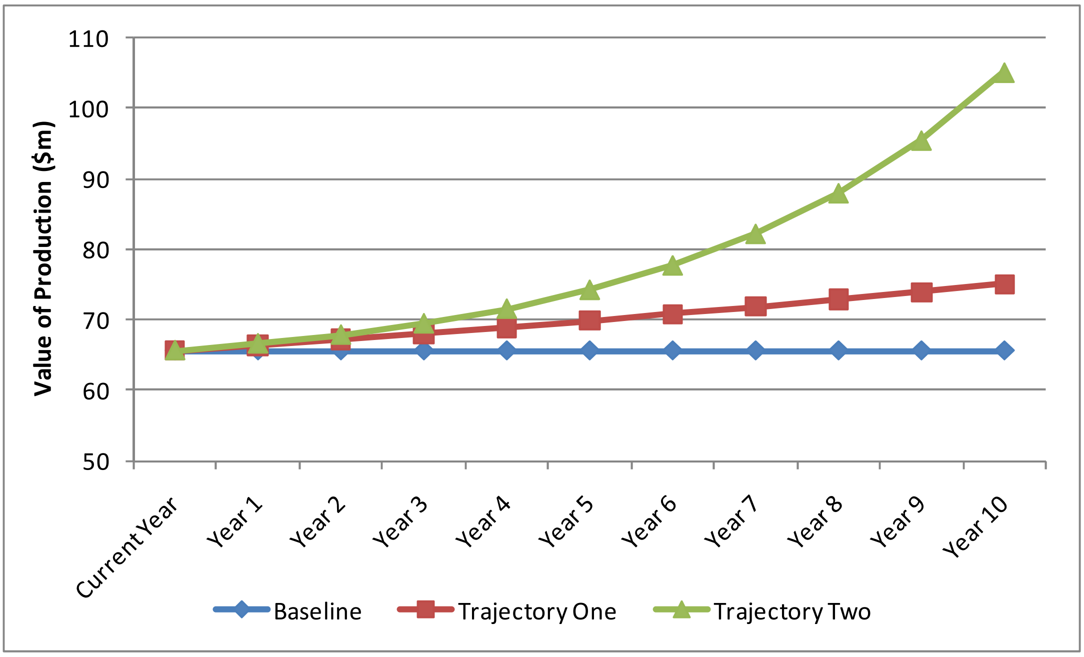
Trajectory	**Description**
Trajectory One – Continued growth in northern Australia (QLD)	Aquaculture production in northern Australia (QLD) continues to grow at approximately 4 per cent per annum).
Trajectory Two – Growth in Barramundi production in the NT.	Barramundi production in the NT grows from its current level to 5,000 tonnes over the next 10 years.

A summary of method and results are below. Detailed results of the analysis are in Appendix One.

Estimates of economic and population impact were based on estimates of aquaculture production and value of production under each scenario. Estimated value of aquaculture output for each development trajectory is in Figure 3.1.

Estimates of total (i.e. direct plus flow-on) regional economic impact were calculated for a 10 year period. Gross regional product (GRP), employment and population impacts for each trajectory are summarised in Figures 3.2 to 3.4. Economic impacts are in nominal terms (i.e. not discounted) an are reported in 2009 dollars.

Figure 3.1 Value of aquaculture production, northern Australia



Source: EconSearch analysis.

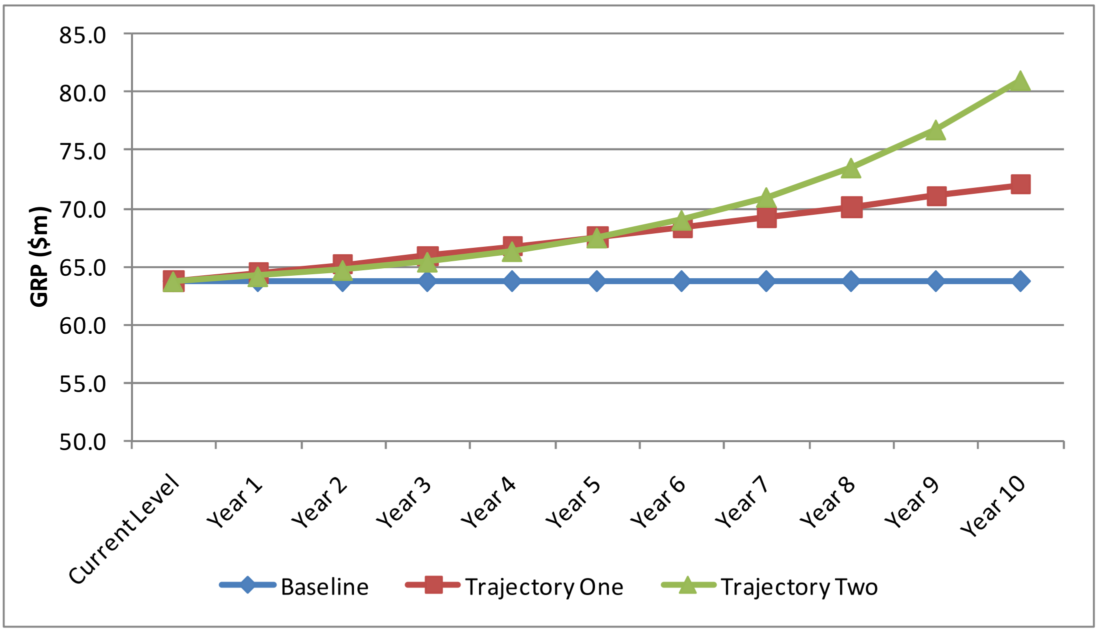
Value of Output

Baseline value of aquaculture output is maintenance of the current level of production and value of production (in real terms) over the next 10 years. Value of aquaculture production was estimated to be approximately $65.6 million in 2006/07 (Figure 3.1).

Over the last five years the total aquaculture production in northern Australia (QLD) has increased by 14 per cent (approximately 4 per cent per annum). Estimates of economic and population impact for trajectory one were based on the assumption that aquaculture production in northern Queensland would continue to grow at this level over the next ten years. Under trajectory one, aquaculture output remains at the baseline level in the remainder of northern Australia. Total value of aquaculture production in northern Australia increases from its current level ($65.6 million) to $75.0 million after 10 years, an increase of 14 per cent overall (Figure 3.1).

Under trajectory two, barramundi production in northern Australia (NT) increases to 5,000 tonnes over 10 years. The value of this production, based on current prices, is estimated to be approximately $42.9 million. Under this scenario the total value of aquaculture output reaches $105.1 million by year 10. This level of output is 60 per cent above existing levels of output (Figure 3.1).

Figure 3.2 GRP impacts of northern Australia aquaculture development trajectories [a]



Source: EconSearch analysis.

Gross Regional Product

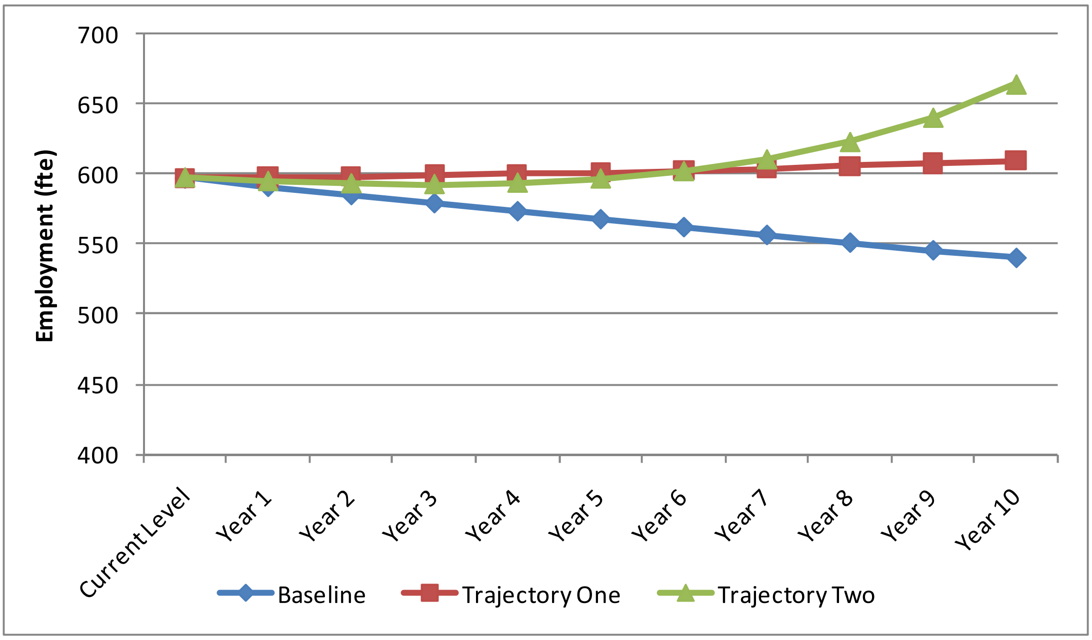
The current contribution of the aquaculture industry to northern Australia is approximately $64 million in GRP, which represents around 0.4 per cent of regional economic activity. [3]

If aquaculture production increases in line with trajectory one, total GRP attributable to the aquaculture sector will increase from $64 million to almost $72 million by year 10, an increase of approximately 13 per cent (Figure 3.2).

Under trajectory two, total GRP in northern Australia attributable to growth in aquaculture output would increase by $17 million after 10 years, an increase of 27 per cent above current levels (Figure 3.2).

[3] Gross regional product in northern Australia was estimated to total approximately $15 billion in 2006/07.

Figure 3.3 Employment impacts of northern Australia aquaculture development trajectories



Source: EconSearch analysis.

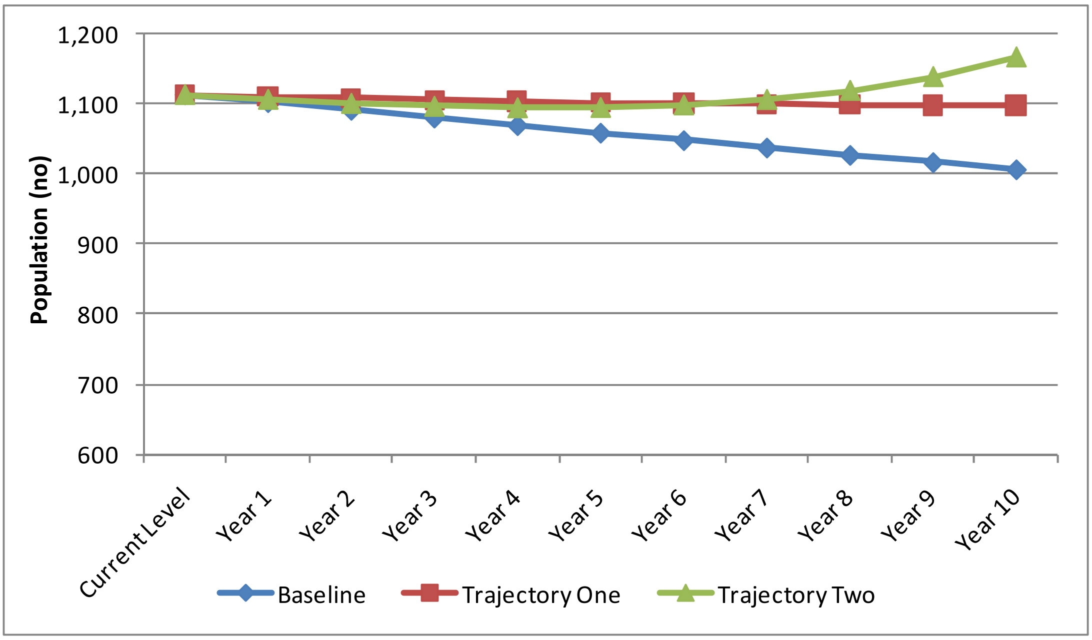
Employment and Population

Employment currently generated by the aquaculture sector, directly and indirectly, is estimated to be around 600 fte. This represents approximately 0.4 per cent of the regions total labour force.

If aquaculture production in northern Australia were to stay at current levels, aquaculture related employment would decline over the next 10 years. This decline would be expected because of labour productivity improvements across all sectors (Figure 3.3). Related to the decline in employment would be a decline in population in northern Australia (Figure 3.4) on the assumption that individuals leaving the industry also leave the region with their dependents. If capital otherwise invested in aquaculture were invested in other sectors with similar capital/labour ratios, this would not happen.

After 10 years of growth under trajectory one, total employment would be 13 per cent higher than if the current level of output continued. Under trajectory one there would be a net increase in employment of approximately 70 ftes by year 10 (Figure 3.3). Associated with this increase in employment would be an increase in regional population above baseline of 90 persons by year 10 (Figure 3.4).

Figure 3.4 Population impacts of northern Australia aquaculture development trajectories



Source: EconSearch analysis.

Under trajectory two, net employment is estimated to increase by around 120FTEs after 10 years. Total aquaculture related employment would be approximately 23 per cent higher under trajectory two than if aquaculture production remained at its current level (Figure 3.3). Associated with the increase in employment would be an increase in population above the baseline of approximately 160 persons by year 10 (Figure 3.4).

4. IF THE POTENTIAL DEVELOPMENT TRAJECTORIES WERE TO OCCUR, WHAT WOULD BE REQUIRED TO MAXIMISE THEIR POSITIVE IMPACTS?

Potential positive impacts associated with the development trajectories (section 3) are:

- Increased income for those employed in aquaculture enterprise
- Increased income for employees and businesses in support services and industries that grow as a result of aquaculture development
- Reduced costs for residents and businesses using improved transport and infrastructure networks
- Residents and businesses benefit from regional economic development resulting in improved and expanded services and facilities
- Existing aquaculture operators benefit from increased research and development potentially resulting in productivity improvements.

Measures to maximise these impacts are summarised in Table 4.1.

Table 4.1 Measures to maximise positive impacts of commercial fishing and aquaculture development

Impact	Practices	Infrastructure	Regulations and Incentives
Increased income for those employed in aquaculture enterprise.	Encourage training, skills development and employment of local population.		The positive impacts of the aquaculture development trajectories cannot be realised if the aquaculture development does not occur due to lack of government approval. The speed at which approval for a development is granted also has the potential to impact the benefits derived from aquaculture development trajectories.
Increased income for employees and businesses in support services and industries	Incorporate local produce into retail and food outlets to encourage purchase of local goods. Encourage diversification of existing local businesses to cater for additional demand from aquaculture development.		
Reduced costs for residents and businesses using improved transport and infrastructure networks	Design road and other transport infrastructure to suit both aquaculture and resident/local business needs. Encourage development by other complimentary businesses with similar infrastructure needs.		
Residents and businesses benefit from regional economic development resulting in improved and expanded services and facilities	Ensure services and facilities are designed to meet the needs of aquaculture development as well as residents and existing businesses.		
Existing aquaculture operators benefit from increased research and development potentially resulting in productivity improvements	Consultation with existing operators regarding research needs and potential.		
Local businesses benefit from re-investment of aquaculture profits.			

5. IF THE POTENTIAL DEVELOPMENT TRAJECTORIES WERE TO OCCUR, WHAT WOULD BE REQUIRED TO MINIMISE THEIR NEGATIVE IMPACTS?

The potential negative impacts associated with the development trajectories (section 3) include:

- Locally, increases in benefits to a few, increased costs for many (local capacity building)
- Potential loss of amenity value at aquaculture development sites
- Competition between commercial and recreational fishers (particularly those targeting barramundi) leading to pressure on stocks and a decrease in recreational fishing visitors
- Interaction/conflict with other land and water users potential implications for downstream water users
- Ecosystem damage from aquaculture development and operation
- Damage to habitat and stocks from commercial fishing (including by-catch).

Measures to maximise these impacts are summarised in Table 5.1.

Table 5.1 Measures to minimise negative impacts of commercial fishing and aquaculture development

Impact	**Practices**	**Infrastructure**	**Regulations and Incentives**
Locally, increases in benefits to a few, increased costs for many (local capacity building)	Invest in regional education and skills training. Encourage co-investments between the region and externally-based businesses.		
Potential loss of amenity value at aquaculture development sites.		Locate any roads and other infrastructure to blend with surrounds.	Ensure planning and approval process considers amenity value of site.
Competition between commercial and recreational fishers (particularly those targeting barramundi) leading to pressure on stocks and a decrease in recreational fishing visitors.			Ensure fisheries are managed to ensure long-term sustainability of stocks. Fisheries management plans and legislation should consider all users of fisheries resources including commercial, recreational and Indigenous.
Interaction/conflict with other land and water users potential implications for downstream water users.	Locate development adjacent to complementary land and water users.	Ensure water supply and waste disposal systems are designed to meet the needs of all users.	
Ecosystem damage from aquaculture development and operation.	Adopt practices that minimise damage to ecosystem.		Ensure planning and approvals process considers environmental and ecosystem impacts.
Damage to habitat and stocks from commercial fishing (including by-catch)	Adopt practices that minimise damage to ecosystem.		Monitor effectiveness of existing by-catch reduction regulations/methods and modify where necessary.

6. WHAT ARE THE CRITICAL KNOWLEDGE GAPS

6.1 Biophysical

Gaps in knowledge about climate change, aquifer behaviour, river flows and ecological responses are addressed by Cresswell (2009), and Pusey and Kennard, (2009), including the consequences for wild fish stocks. Some of this knowledge is also fundamental to sustainable aquaculture development. Research on the impact of potential ecosystem damage (i.e. from fish escapes, disease outbreak, waste, etc.) and on how to minimise adverse effects will help in developing and implementing aquaculture development policies.

6.2 Economic

A better understanding of the benefits and costs associated with production systems, species and other factors that may affect the profitability of an aquaculture enterprise may assist in encouraging investment in the industry. A better understanding of markets and future market needs may boost aquaculture investor and developer confidence.

6.3 Social

Better understanding of how to minimise the negative social impacts of aquaculture and commercial fishing and how to enhance positive impacts. There has been limited research undertaken on the social impacts of aquaculture. A greater understanding of the community support for aquaculture is required. Research on the motivations and behaviours of recreational fishers, and on their impacts on stocks will help shape fisheries policies. The potential for motivating commercial fishers to manage stocks through tradable access rights is worth investigating.

REFERENCES

AFMA. (2009). Retrieved from http://www.afma.gov.au

Australian Aquaculture Industry Action Plan 2005. National Aquaculture Council Consultation Paper, http://www.australian-aquacultureportal.com/ action_agenda/pdf/ActionPlan_011105.pdf

Australian Bureau of Agricultural and Resource Economics (ABARE). (2006). *Australian Fisheries Statistics 2005.* Canberra: ABARE.

Australian Bureau of Agricultural and Resource Economics (ABARE). (2009). *Australian Fisheries Statistics 2008.* Canberra: ABARE.

Bitomsky J. (2008) Scoping analysis: redclaw industry development. Available through Kleinhardt Business Consultants or Primary Industries and Fisheries (QLD)

Brodie, J., Mitchell, A.W. 2005, Nutrients in Australian tropical rivers: changes with agricultural development and implications for receiving environments, Marine and Freshwater Research, Vol.56, pp.279-302.

Bureau of Infrastructure, Transport and Regional Economics (BITRE). (2009). *Northern Australia Statistical Compendium.* Canberra: BITRE.

Carpenter, S. R., and Biggs, R., 2009. Freshwaters: Managing Across Scales in Space and Time. Pages 197-220 in Chapin, F. Stuart, III, Kofinas,, G.P., and Folke, C., *Principles of Ecosystem Stewardship: Resilience-based Natural Resource Management in a Changing World*. Springer, New York.

Clark, E., Abel, N., Measham, T., Morison, J., and Rippin, L., 2009. Water Based Tourism and Recreation. Chapter 11, this report.

Clark, E., Morison, J., and Ferris, M., 2009. Modelling the Economic and Employment Impacts of Water Resource Development in Northern Australia.

Cresswell, R., et al., 2009. Water Resources. Chapter 1, this report.

Collins, A, Russell, B, Walls, A, Hoang, T 2005, *Inland Prawn Farming; Studies into the Potential for Inland Marine Prawn Farming in Queensland*, Available: 142 http://www2.dpi.qld.gov.au/extra/pdf/far/inlandprawnfarming.pdf

Collins, A. Russell, B. Walls, A. and Hoang, T. 2005, *Inland Prawn Farming – Studies into the Potential for Inland Marine Prawn Farming in Queensland,* prepared for Queensland Department of Primary Industries and Fisheries.

DBIRD. (2004). Fishery Status Reports 2003. Darwin: Department of Busines, Industry and Resource Development, Northern Territory.

Department of Agriculture Fisheries and Forestry 2003, *The National Recreational and Indigenous Fishing Survey*, Available: http://www.affa.gov.au/corporate_docs/publications/pdf/fisheries/final_recsurvey_report.pdf

Department of Primary Industries and Fisheries and Department of Tourism, Regional Development and Industry

DPIFM. (2005). Fishery Status Reports 2004. Darwin: Department of Primary Industry, Fisheries and Mines, Northern Territory.

DPIFM. (2006). Fishery Status Reports 2005. Darwin: Deparment of Primary Industry, Fisheries and Mines, Northern Territory.

DPIFM. (2007). Fishery Status Reports 2006. Darwin: Department of Primary Industry, Fisheries and Mines, Northern Territory.

DRDPIFR. (2008). Fishery Status Report 2007. Darwin: Deparment of Regional Development, Primary Industry, Fisheries and Resources, Nothern Territory.

Fletcher, W. J., & Head, F. (2006). *State of the Fisheries Report 2005/06.* Perth: Department of Fisheries, Western Australia.

Fletcher, W. J., & Santoro, K. (2007). *State of the Fisheries Report 2006/07.* Department of Fisheries, Western Australia.

Fletcher, W. J., & Santoro, K. (2008). *State of the Fisheries Report 2007/08.* Perth: Department of Fisheries, Western Australia.

Greiner, R. Herr, A. and Larson S. 2006, *Literature review of relevant socio-economic information available for the Northern Planning Area,* prepared for the National Oceans Office Branch, Department of the Environment and Heritage, CSIRO Sustainable Ecosystems: Townsville.

Henry, G.W. and Lyle, J.M. (eds) 2003. *The National Recreational and Indigenous Fishing Survey*, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra.

Lovelock CE, Ellison J (2007) Vulnerability of mangroves and associated tidal wetlands of the GBR to climate change. In "Climate Change and the Great Barrier Reef", J. Johnson, P Marshall (eds), Great Barrier Reef Marine Park Authority, Townsville, Australia.

Mazur, N. A. and Curtis, A. L. (2006). Risk Perceptions, Aquaculture, and Issues of Trust: Lessons From Australia. *Society & Natural Resources ,* 19 (9), pp. 791-808

McCluskey, S M, and Lewison, R L, 2008. Quantifying fishing effort: a synthesis of current methods and their applications. Fish and Fisheries 9, 188-200

Minnecon and Burke Pty Ltd, 2004, Scoping Study Report in Opportunities for Indigenous Aquaculture in North Queensland.

Ozestuaries n.d., *Economic value of estuarine commercial fisheries*, Available: http://www.ozestuaries.org/indicators/econ_value_commercial_fisheries.jsp

Penn, J. W., Fletcher, W. J., & Head, F. (2005a). *State of the Fisheries Report 2004/05.* Perth: Department of Fisheries, Western Australia.

Penn, J. W., Fletcher, W. J., & Head, F. (2005b). *State of the Fisheries Report 2003/04.* Perth: Department of Fisheries, Western Australia.

Policy for the management arrangements for the commercial harvesting and use of juvenile eels (February 2006) is available on the Queensland Primary Industries and Fisheries website at www.dpi.qld.gov.au

Pusey, B., and Kennard, M., 2009. Aquatic Systems. Chapter 3, this report.

Queensland Oyster Industry Development Plan (2005) is available on the Queensland Primary Industries and Fisheries website at www.dpi.qld.gov.au

Queensland Oyster Industry Development Plan: Implementation Report (2007) is available on the Queensland Primary Industries and Fisheries website at www.dpi.qld.gov.au

Queensland Primary Industries and Fisheries (2008) *Queensland barramundi farming status report (2008) The State of Queensland*, DEEDI

Seafood Farming Services 2004, *Investment Risk Analysis for Evaluating Inland Saline Aquaculture Production Systems and Species.*

The Prawn Industry Development Plan is available on the Queensland Primary Industries and Fisheries website at www.dpi.qld.gov.au

APPENDIX 1 ECONOMIC IMPACTS OF AQUACULTURE DEVELOPMENT

Appendix Table 1.1 Economic and population impact of aquaculture development trajectories

	Year 5			Year 10		
	GRP ($m)	Employment (fte)	Population (no)	GRP ($m)	Employment (fte)	Population (no)
Baseline						
Direct impact	39	376	706	39	358	672
Flow-on impact	24	192	353	24	182	336
Total impact	**64**	**568**	**1,059**	**64**	**540**	**1,007**
Trajectory One						
Direct impact	42	401	738	45	409	739
Flow-on impact	26	200	364	27	200	359
Total impact	**68**	**601**	**1,102**	**72**	**610**	**1,098**
Trajectory Two						
Direct impact	42	393	727	39	431	765
Flow-on impact	26	203	368	42	234	402
Total impact	**68**	**596**	**1,095**	**81**	**664**	**1,166**

Source: Clark et al. (2009)