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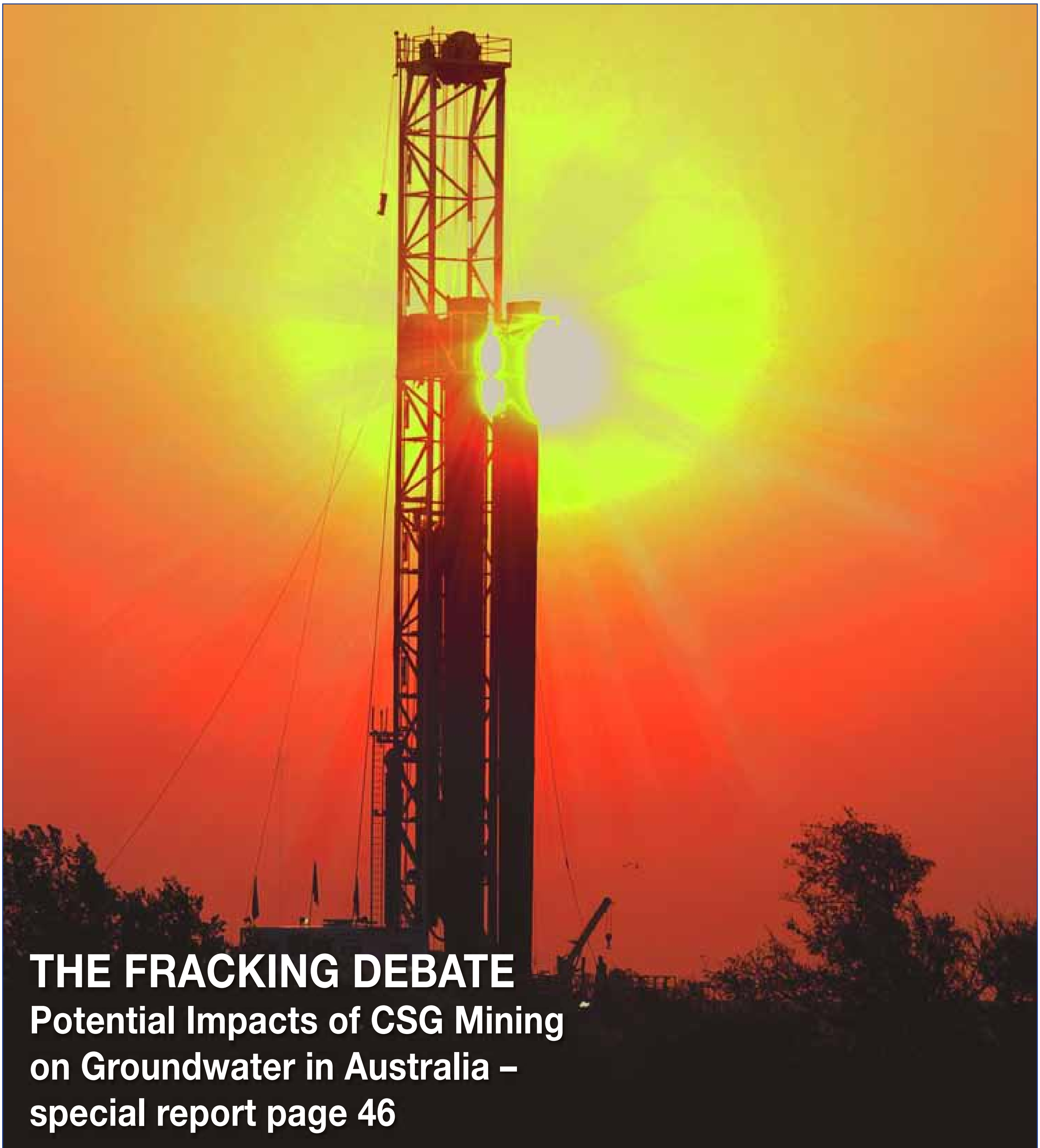

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CLIMATE CHANGE PROSPECTS FOR FRESHWATER FISHERIES IN THE TROPICAL PACIFIC

An overview of production and management strategies to adapt to population growth and climate change

P Gehrke, M Sheaves, B Figa, D Boseto, J Terry, J Wani, J Ellison

Abstract

Freshwater fisheries in the tropical Pacific play an important role in the food security, livelihoods and culture of people living in inland areas. Human populations in the region are projected to increase by 50% by 2030, increasing the importance of fresh fish as a source of animal protein for human nutrition. A priority of fisheries management is, therefore, to increase fisheries production to meet demand, and to develop strategies to maintain food security and government revenue in the face of climate change.

Analysis of information on freshwater environments and projections for B1 and A2 climate change scenarios to 2035 and 2100 identified that equatorial zones are likely to receive an increase in rainfall of up to 20%, leading to increased river discharge of 33% by 2050 in places. In subtropical zones, rainfall is projected to decrease by as much as 20%. Increased river discharge and area of freshwater habitats are likely to dominate other responses to climate change, resulting in increases in fish production by as much as 12.5% by 2100. Sound catchment management to minimise adverse effects on fish habitats from economic development activities will be required to ensure that this potential benefit from climate change can be achieved.

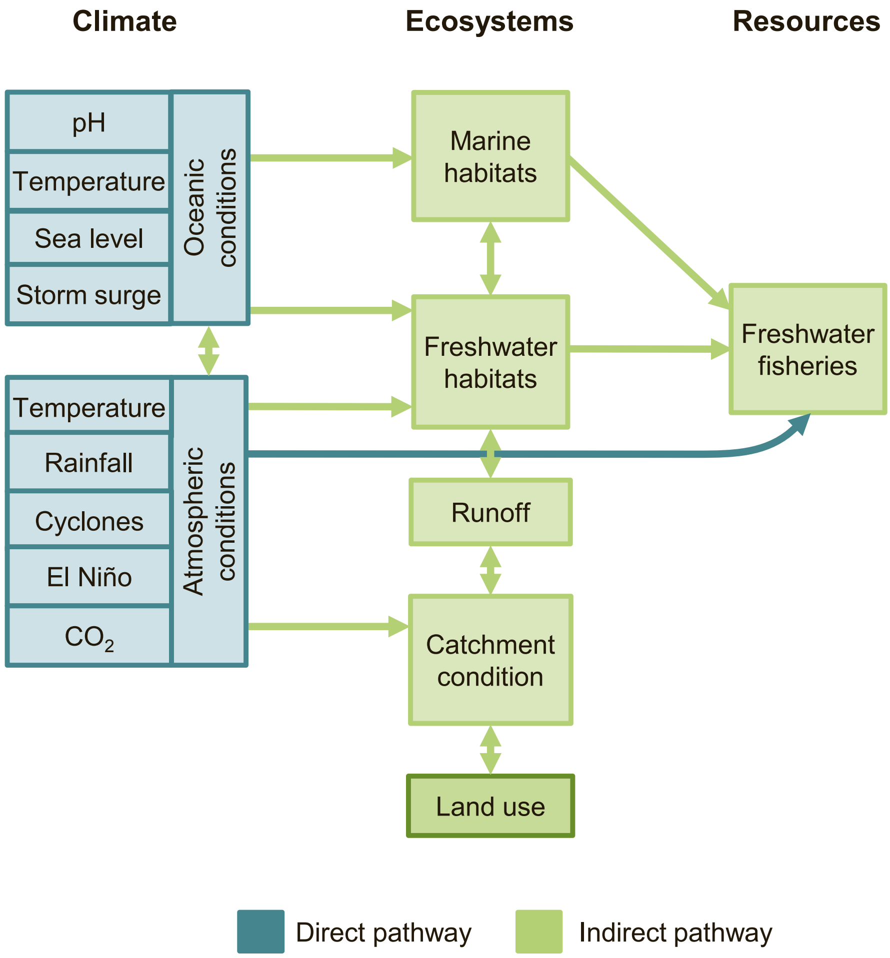

Figure 1. Conceptual representation of the direct and indirect pathways through which climate change may affect freshwater fisheries.

Introduction

Freshwater fisheries in the tropical Pacific region are much more important than most people realise. The annual catch from freshwater alone is estimated at 24,000 tonnes per year, and provides around 4% of GDP derived from fisheries resources, despite river catchments representing less than 1% of the area fished. Catches of freshwater fish from Papua New Guinea (PNG) alone are four times greater than the total freshwater catch in Australia. The largest catches come from the high islands in Melanesia (PNG, Solomon Islands, Vanuatu and Fiji), which support the largest rivers and lakes in the region.

Consumption of freshwater fish in parts of PNG is as high as 100kg per person each year, demonstrating the importance of fish to the livelihoods, nutrition and culture of people living near rivers and lakes. Human populations in the Pacific region are projected to grow by 50% by 2030, generating increasing demand for fish as the main source of animal protein to maintain basic nutritional requirements (Bell *et al*., 2011). At current catch rates, there is likely to be a shortfall of fish to meet this demand. The governments of Pacific island countries and territories are currently developing strategies to increase fish catches to maintain domestic food security and government revenue through sale of fishing licences and fish exports.

However, current projections for climate change suggest that changes in oceanic and atmospheric conditions may have serious consequences for habitats that support major marine fisheries within the region. Freshwater fisheries may also be affected through a combination of pathways that affect fish directly, as well as indirect pathways through effects on catchment processes, habitats and land use interactions (Figure 1). In addition, migratory species with complex life cycles that spend part of their lives at sea will be affected by climate impacts on both marine and freshwater habitats.

This paper reviews available information to assess the vulnerability of freshwater habitats and fisheries to climate change, as part of a larger study of fisheries and aquaculture across the tropical Pacific (Bell *et al*., 2011).

Climate Change Vulnerability Assessment

The vulnerability of freshwater fisheries was assessed qualitatively by reviewing and synthesising available information on the potential direct and indirect impact pathways represented in Figure 1. Effects of oceanic conditions on marine habitats are described elsewhere (Bell *et al*., 2011).

Climate change projections were generated for four scenarios, by applying the low emissions B1 and the high emissions A2 storylines at timeframes of 2035 and 2100 (Lough *et al*., 2011). The resolution of existing atmospheric and oceanic climate models does not currently permit downscaling to individual islands and river catchments. Accordingly, a qualitative analysis was undertaken based on overarching atmospheric and oceanic climate projections, consideration of local island climate patterns, and application of a geomorphological and geological template to capture catchment hydrological processes that translate rainfall into runoff and river flow. Projected climate change effects for the region are given in Table 1.

Table 1. Summary of projected climate change effects for the tropical Pacific region (Lough *et al.*, 2011; Ganachaud et al., 2011).

Climate variable	2035		2100	
	B1	A2	B1	A2
Surface temperature (°C)	0.5 - 1.0	0.5 - 1.0	1.0 - 1.5	2.5 - 3.0
Rainfall – equatorial regions	+ 5 - 15%	+ 5 - 20%	+ 10 - 20%	+ 10 - 20%
Rainfall – subtropical regions	- 5 - 10%	- 5 - 20%	- 5 - 20%	- 5 - 20%
Cyclones	Possible decrease in frequency, but increased intensity			
El Niño events	Continuing influence but frequency and intensity uncertain			
Sea level (cm)	+ 20 – 30	+ 20 – 30	+ 70 – 110	+ 90 – 140

Freshwater habitats were differentiated according to elevation to distinguish montane, slopes and lowland rivers, as well as lakes and floodplain wetlands. Islands were further classified according to geology. High islands with volcanic geology generate significant runoff resulting in perennial flowing rivers. Low islands with porous limestone geology exhibit high infiltration rates with low runoff, resulting in few flowing rivers or standing freshwater habitats. Existing information on rainfall and runoff, hydrology, water quality, physical habitat form and geomorphological processes was reviewed and synthesised to describe the diversity of freshwater ecosystems in the Pacific, and their potential responses to climate change scenarios.

Information on freshwater fisheries in the Pacific islands is generally poor, with the best studies coming from the Fly and Sepik-Ramu regions of PNG (Blaber *et al*., 2009; Coates, 1993). Accounts from elsewhere are predominantly derived from biodiversity surveys and anecdotal accounts (Gillett, 2009). Data on fishing effort is characteristically lacking. Fish habitat use and potential responses to climate change were derived from published studies from the Pacific, or from neighbouring regions or closely related species where direct information was not available.

Vulnerability of habitats and fisheries to climate change was assessed using the vulnerability framework (Bell *et al*., 2011). This approach considers exposure to climate change and sensitivity to climatic effects to identify potential impacts, and capacity of habitats and species to adapt to changes in climate. Vulnerability is defined as the remaining impacts following adaptation.

Vulnerability of freshwater habitats and fisheries resources were integrated to develop recommendations to minimise remaining risks to freshwater environments and fisheries to ensure food security for inland populations into the future.

Freshwater Habitats

High islands in the tropical Pacific display an array of river types based on catchment area, drainage density, discharge and geomorphology, which determine the habitats and the fish species that occur. The three longest rivers in PNG, the Sepik-Ramu, Fly and Purari, have a combined catchment area of more than 200,000 km^2, with flows that rank among the highest in the world. Smaller rivers, however, have short (< 100 km), straight, steep

PHOTO: BOGA FIGA

Figure 2. Large floodplain lakes such as Lake Owa in Papua New Guinea are likely to expand as a result of climate change.

Figure 3. Papuan black bass are highly sought after in the subsistence fishery in southern Papua New Guinea.

channels in comparison, with small, narrow catchments and few tributaries. The steep terrain and channel gradients promote rapid runoff and flash flooding (Gehrke *et al*., 2011a).

Lowland river reaches have more subdued terrain, with alluvial terraces and floodplains. The Fly River floodplain is the largest wetland in the region, covering an area of 4.5 million hectares (Figure 2). Despite the tropical climate, most rivers have modest discharge because of their small catchment area, but even the smallest rivers tend to flow continuously.

River flows vary on a two- to five-year time scale under the influence of the El Niño Southern Oscillation. During El Niño events, the central and eastern Pacific experience increased rainfall, whereas the western part of the region experiences extended droughts. The La Niña events that follow El Niño events typically bring heavy rainfall, cyclones and flooding, which dominate ecological processes in freshwater habitats. Small rivers typically have low biodiversity, and recolonisation after disturbance can change species composition (Gehrke *et al*., 2011a).

Importance of habitat connectivity to fisheries

Many fish species in the Pacific region migrate between freshwater and the sea to complete their life cycle. Adult barramundi migrate to sea to spawn, and larvae and juveniles migrate to floodplain wetlands before returning to the river channel where they mature. Connectivity between habitats is critical to most fisheries species in tropical rivers.

Fish depend on a number of food webs for energy and growth across different habitats, including planktivorous pathways; epiphyte grazer pathways; terrestrial carbon pathways based on riparian vegetation and detritus; and pathways based on insects and fruits from streamside vegetation (Storey and Yarrao, 2009).

Indirect effects

Rainfall

Climate models for the Pacific emphasise ocean-atmosphere interactions as the driver of island climates, but do not account for the effects of high islands on local weather (Lough *et al*., 2011), creating uncertainty in rainfall and flow projections. Despite the low spatial resolution of rainfall projections, most rivers will receive more runoff because of the expected increases in rainfall (Table 1). The southwest of the region around New Caledonia may expect a decline in rainfall of up to 20% during winter by 2100, increasing the seasonal variability of river flow. The southeast regions may expect more uniform rainfall, with a 5% to 20% decrease over summer, and a 20% increase in winter under the A2 scenario.

Higher rainfall will lead to increased magnitude and duration of flows. River discharge is estimated to increase by 9% in the Fly River and 33% in the Sepik River by 2050 under the A2 scenario (Palmer *et al*., 2008), increasing further towards 2100. These changes will increase habitat availability and connectivity. Habitat quality will also be affected by the timing, intensity, frequency and variability of rainfall and resulting effects on the flow regime. Reduced rainfall in the subtropical Pacific will decrease river flow in New Caledonia and French Polynesia, leading to a narrowing of river channels and reduced connectivity between habitats.

Cyclones

Cyclones are expected to become less frequent, but more intense, with more damaging winds and larger storm surges. Rising sea levels will not affect rivers uniformly, because islands differ in their evolution stages between uplifting, subsidence, and deposition of sediments on floodplains. Saline intrusion into freshwater habitats as a result of rising sea levels will be accentuated by cyclonic storm surges, and may be countered by increased freshwater flow.

El Niño Southern Oscillation

El Niño events will remain a strong feature of the tropical Pacific climate, producing droughts with reduced river flow and low habitat availability as floodplain habitats become disconnected from rivers or dry completely. It is anticipated that the extreme climatic conditions in El Niño cycles will become more pronounced, leading to drier dry periods, and wetter wet years (Lough *et al*., 2011). Reduced river flows during El Niño droughts enable salt water to penetrate further into freshwater habitats. These changes are projected to translate into increased variability in availability of freshwater habitats.

Temperature

Increases in surface temperature are difficult to extrapolate directly to freshwaters. Shaded rivers fed by groundwater may experience little change from present-day temperatures, whereas shallow open water wetlands may warm by more than the predicted increase in surface temperature.

Vulnerability of freshwater habitats

Climate change impacts on freshwater systems will be expressed differently from impacts on marine habitats. The dominant concerns for marine habitats and fisheries arise from changes in water quality related to increasing temperature and ocean acidification. In contrast, the greatest changes in freshwater habitats are projected to come from increased water quantity, resulting in a greater area and availability of freshwater habitats (Gehrke *et al*., 2011a). Freshwater habitats in the Pacific region typically experience daily, seasonal and annual variations in water quality that are larger than projected effects of climate change, and have low vulnerability to changes in water quality.

The vulnerability of individual rivers will be determined by the interactions between climate change and the condition of catchment vegetation. Increased water availability, temperature and CO_2 fertilisation effects (McMahon *et al*., 2010) are projected to enhance growth of vegetation, improving the resilience of freshwater ecosystems to the adverse effects of climate change. The moderating effects of catchment vegetation will be reduced in catchments that are affected by urban development, mining, forestry and agriculture. In disturbed catchments, turbidity is expected to increase as a result of increased erosion. Catchments with intact vegetation are likely to experience little change in turbidity because potential increases in sediment transport resulting from increased intensity of runoff will be offset by increased growth of vegetation. The net outcome for turbidity is likely to be site-specific, but over larger spatial scales the changes are projected to be small.

Montane rivers have low vulnerability to habitat changes resulting from increased flow, but will experience elevated water temperatures. At intermediate elevations, slopes reaches have low vulnerability to the expected changes in water temperature and rainfall. Transient negative effects are likely following cyclone damage to catchment vegetation. Lowland rivers have low vulnerability to increased annual discharge. Vulnerability to habitat damage from extreme flows is expected to increase; however, the potential negative effects of these changes may be offset by greater availability of freshwater habitats in the long term.

Vulnerability of lakes is low under the influence of increased rainfall. Floodplain habitats are also likely to be enhanced by increases in rainfall and water temperature. As floodplain vegetation adapts to a wetter climate, however, habitats will become more vulnerable to droughts. Low-lying floodplains, such as the Fly floodplain, are vulnerable to saline inundation from rising sea levels. Floodplains further upstream should be inundated more extensively as rising sea levels force freshwater flows laterally. The most critical feature determining the vulnerability of habitats to increasing temperature, higher rainfall and intense cyclones is the extent of intact catchment vegetation. The ability of rivers to absorb these changes is provided through shading of the water by the forest canopy, and stabilisation of soils through root development.

Projections for subtropical habitats are in the opposite direction, particularly in New Caledonia, where vulnerability to negative impacts is moderate to high by 2100. In New Caledonia, rivers are expected to experience channel reduction and habitat fragmentation because of reduced rainfall. Increased temperature and evaporation make lakes and wetlands highly vulnerable in drought years.

Constraints to habitat adaptation

When the effects of higher temperatures, altered flow and sea-level rise are integrated, equatorial freshwater habitats have a low vulnerability to climate change, and are expected to expand under the influence of increased rainfall for both the B1 and A2 scenarios until 2100. The positive and negative effects on freshwater habitats will be mediated by the way catchments are managed. Physical processes in river systems are strongly driven by runoff and river flow. Where catchment vegetation has been cleared, autonomous adaptive capacity is reduced and vulnerability of habitats increases. The largest increases in habitat availability are likely to occur in floodplains. However, the quality of expanded habitats will be influenced by catchment condition.

Global climate change projections for freshwater habitats (Xenopoulos *et al*., 2005) are consistent with the assessment provided here. Increased river flow makes freshwater habitats in the Pacific especially likely to experience improvements, such as increased habitat availability and complexity in catchments with intact vegetation where erosion and sedimentation rates are low (Victor *et al*., 2004). In well-managed catchments, the adaptive capacity of vegetation may be sufficient to limit erosion and deliver benefits from increased flows. However, where natural vegetation has been removed, the capacity to mitigate the damaging effects of increased runoff and erosion is reduced. The primary constraint to climate adaptation of freshwater habitats is development in catchments to support rapidly growing human populations, which are predicted to grow from 9.86 million in 2010 to 15 million by 2035 (Bell *et al*., 2011).

Freshwater Fisheries Production

Fishing methods used in freshwater are mostly simple, involving traditional gear such as spears, woven baskets and traps, hand collection, poisoning with derris roots, and more elaborate diversion of small streams into rock traps. More recent innovations include monofilament hand lines and gill nets, cast nets, and outboard-powered aluminium punts. Skilled fishers make substantial catches with even relatively simple equipment (Figure 3).

River flow

Fish are sensitive to the magnitude, timing, frequency and duration of flow events, the rate of change in flow, and the seasonality, variability and predictability of flows (Welcomme and Halls, 2004). Barramundi in PNG are expected to be sensitive to changes in flows that influence migration, spawning and availability of nursery habitats. The relationship between flow, fish abundance and catches has been documented for many species, based on habitat availability and food web processes, leading to increased recruitment and cues for fish migration. Increased rainfall that coincides with the timing of spawning, recruitment and migration, is likely to enhance freshwater fish populations. For freshwater species that migrate to sea to breed, increased rainfall during the low flow season is expected to increase habitat availability, and elevated wet season flows will increase access to nursery habitats. Increased river flow is, therefore, projected to increase fish production in equatorial regions.

Water temperature

Warmer temperatures will affect fish production through both direct and indirect pathways. Projected increases in water temperature are unlikely to be lethal to fish. Exposure to high temperatures is most likely in floodplain habitats, where many species tolerate water temperatures above 35°C. In contrast, riverine species tend to inhabit waters below 35°C. Fish production will increase under the influence of enhanced primary production and faster fish growth rates (Downing *et al*., 1990); however, exposure to pollutants from disturbed catchments may reduce fish temperature tolerances (Patra *et al*., 2007). Species that migrate through the sea may expand their distributions as waters warm, with the distribution of barramundi projected to expand southward by 800km (Balston, 2007).

Water quality

Other changes in water quality, such as dissolved oxygen and turbidity, are likely to be site-specific. In stratified lakes, increases in wind action are expected to bring hypoxic water to the surface, resulting in declining fisheries production (O'Reilly *et al*., 2003), while warmer floodplain habitats are also likely to experience reduced oxygen availability, creating a trend towards fish communities dominated by hypoxia-tolerant species.

Vulnerability of fish to turbidity is low in undisturbed catchments, and many species thrive in the naturally turbid lowland reaches of the Fly River. However, clearing vegetation for catchment development predisposes rivers to increased turbidity, leading to changes in primary production, food web processes, and potential changes in the species composition of fish communities.

Synthesis of freshwater fisheries production

Increases in river flow are projected to drive changes in fisheries production (Gillett, 2009; Downing *et al*., 1990). The magnitude, timing, frequency, duration, variability and rate of change in river flows influence the availability and quality of fish habitat, and provide cues for fish migration, reproduction and recruitment. Even so, increased flow will be tempered by other climate effects, especially in disturbed catchments. The benefits to fish production are difficult to quantify because of uncertainties in the climate models and their limited ability to project changes at the catchment scale. In the absence of down-scaled climate modelling and hydraulic models of habitat availability, changes in biological fish production (Table 2) are estimated to be approximately proportional to changes in habitat areas as a result of increased rainfall (Gehrke *et al*., 2011b). This estimation process is appropriate for most catchments in the Pacific region because of the low intensity of catchment development outside urban areas. Adverse interactions between climate change and land use are likely to be significant at a local scale, but at the regional scale the net response is projected to be positive.

Table 2. Changes in biological production of freshwater fisheries in the tropical Pacific, under B1 and A2 scenarios by 2035 and 2100, derived from projected changes in habitat availability as a result of variation in rainfall. Values in parentheses indicate projected range (likelihood of occurrence 29%–66%, with 33%–66% confidence).

Pacific Island country or territory	Recent production (t y^{-1})	Projected change (%)			
		2035		2100	
		B1	A2	B1	A2
		Melanesia			
Fiji	4,146	0 (-5 – 5)	0 (-5 – 5)	0 (-5 – 5)	12.5 (5 – 20)
New Caledonia	10	2.5 (-5 - 10)	0 (-5 – 5)	-2.5 (-10 – 5)	0 (-20 – 20)
PNG	17,500	0 (-5 – 5)	2.5 (-5 – 10)	7.5 (-5 – 20)	7.5 (-5 – 20)
Solomon Islands	2,000	0 (-5 – 5)	2.5 (-5 – 10)	7.5 (-5 – 20)	7.5 (5 – 10)
Vanuatu	80	0 (-5 – 5)	2.5 (-5 – 10)	0 (-5 – 5)	7.5 (5 – 10)
		Micronesia			
Federated States of Micronesia	1	0 (-5 – 5)	0 (-5 – 5)	0 (-5 – 5)	7.5 (-5 – 20)
Guam	3	0 (-5 – 5)	2.5 (-5 – 10)	2.5 (-5 – 10)	7.5 (-5 – 20)
Palau	1	0 (-5 – 5)	0 (-5 – 5)	2.5 (-5 – 10)	7.5 (-5 – 20)
		Polynesia			
American Samoa	1	0 (-5 – 5)	0 (-5 – 5)	0 (-5 – 5)	2.5 (-5 – 10)
Cook Islands	5	2.5 (-5 – 10)	2.5 (-5 – 10)	2.5 (-5 – 10)	7.5 (-5 – >20)
French Polynesia	100	2.5 (-5 – 10)	2.5 (-5 – 10)	2.5 (-5 – 10)	7.5 (-10 – >20)
Samoa	10	0 (-5 – 5)	0 (-5 – 5)	0 (-5 – 5)	2.5 (-5 – 10)
Tonga	1	0 (-5 – 5)	0 (-5 – 5)	2.5 (-5 – 10)	7.5 (-5 – >20)

Available data allow only crude projections of fisheries yield. Projected increases in biological production suggest that fisheries production may increase by up to 2.5% in 2035, by 2.5 to 7.5% under B1 in 2100, and by 7.5% for the A2 scenario in 2100 (Table 2). Achieving these increases will depend on the ability to implement sustainable fishing practices to avoid over-fishing, and to mitigate other threats to fisheries resources, including invasive species and habitat degradation arising from inappropriate catchment management. Since pressure from population growth is expected to be greatest in urban areas where reliance on freshwater fisheries is low, it is anticipated that fisheries production in rural catchments will not be adversely affected by increased fishing pressure (Bell *et al*., 2011).

Strengthening of environmental legislation, including customary management practices (Ellison, 2009) is anticipated to reduce the adverse impacts of catchment development into the future. Considering the magnitude of climate impacts and prospects for population growth, it is possible that the impacts of climate change will be overshadowed by activities such as mining, logging and agriculture, and that ineffective management of these activities may predispose freshwater fisheries production to the more damaging effects of climate change (Ficke *et al*., 2007).

Conclusions

The limited information on freshwater fisheries and ecosystems in the tropical Pacific region presents a major source of uncertainty in this assessment. This limitation makes it difficult to develop quantitative assessments of the likely impacts of any threat to fisheries production. The low resolution of existing climate models also creates uncertainty at the scale of individual islands, catchments, and rivers. Down-scaling of climate models is needed to allow more rigorous assessment of changes in freshwater habitats, and vulnerability of fisheries production.

Modelling case studies of habitat changes in disturbed and intact catchments and resulting effects on fisheries production are required to quantify the comparative magnitude of climatic and human impacts.

Engagement of non-fisheries sectors in habitat management is required to sustain freshwater fisheries, in addition to customary approaches to fisheries management. A cross-sectoral approach to ecosystem-based management will provide an opportunity to maximise the benefits, and to minimise the adverse effects of climate change on fisheries.

Careful management of freshwater fisheries, especially fishing effort and available gear, will be required to sustain catches, and this will include obtaining information on catch and effort to guide decision making by governments, non-government authorities and customary managers.

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