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FINAL DETERMINATION

Human-caused climate change as a Key Threatening Process

The Fisheries Scientific Committee, established under Part 7A of the *Fisheries Management Act 1994* (the Act), has made a final determination to list 'Human-Caused Climate Change' in NSW as a KEY THREATENING PROCESS in Schedule 6 of the Act.

The listing of Key Threatening Processes is provided for by Part 7A, Division 2 of the Act.

The Fisheries Scientific Committee has found that:

1. The distribution of most species, populations and communities is determined, at least at some spatial scale, by climate.
2. Climate change has occurred throughout geological history and has been a major force for evolution (Pagani *et al.* 2005, Kurschner *et al.* 2008). It is now evident that in recent times (the so-called "Anthropocene"), 63% of greenhouse gases responsible for climate change originate from human-induced carbon dioxide (Hofmann *et al.* 2006) and human-caused climate change is substantially affecting species, populations and communities of aquatic animals and vegetation throughout the world.
3. There is physical evidence that human-caused climate change is affecting biodiversity globally, in terrestrial, freshwater and marine systems (Meehl *et al.* 2007, Rosenzweig *et al.* 2007). The International Panel on Climate Change (IPCC 2007) stated that "observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature changes". The IPCC 4th Assessment Report in 2007 listed 28,671 significant changes in biological systems globally, with 90% of the changes consistent with warming.
4. The major human-caused climate stressors listed by Hobday & Matear (2005), Hobday *et al.* (2006), IPCC (2007) and relevant to aquatic systems are: (1) increasing sea surface temperature; (2) greater warming of water around 500m depth; (3) increases in incident solar radiation; (4) a rise in sea level; (5) greater stratification and a shallowing of the mixed layer, causing a reduction in nutrient inputs from deeper waters; (6) an increase in surface winds resulting in extreme wind events; (7) a general decline in surface currents; (8) slowing down of the thermohaline circulation; (9) a change in seawater chemistry, including a marked decline in pH; and (10) changing rainfall patterns causing fluctuations in salinity.
5. It is now widely accepted that disproportionately large impacts on biodiversity will occur to communities where foundation species (i.e., those that form a habitat structure for other species) have undergone range shifts in response to climate change (Hughes 2000, Harley *et al.* 2006). Many ecologically-important species are predicted to shift in abundance, distribution and seasonality in response to climate change, especially near the poles, due to latitudinal shifts in bioclimate envelopes in both terrestrial (as reviewed in Hughes 2003) and marine systems (e.g., Hijmans *et al.* 2006, Ling *et al.* 2009).
6. Recent climatic events are affecting the survival, development, phenology, physiology and ecology of a wide range of marine species (Wespestad *et al.* 2000, Walther *et al.* 2002, Fabry *et al*. 2008). There is a high probability that such climatic impacts on

Port Stephens Fisheries Institute, Locked Bag 1, Nelson Bay NSW 2315
Phone: (02)4982-1232 Fax: (02)4982-1107 Email:fsc@industry.nsw.gov.au

aquatic species will result in widespread cascading effects throughout ecosystems and complex interactions among species (IPCC 2007). The vulnerability of marine life to climate change will depend on the species in question, the community they inhabit, and their location. Species most at risk include those with long generations, poor mobility, direct development and those already affected by, or sensitive to, non-climate change stressors such as fishing, pollution and habitat degradation (Hughes & Westoby 1994, Walther *et al.* 2002, IPCC 2007). Poleward shifts may not be "smooth" due to the complexity of many interacting climatic factors, and may instead result in localised extinctions at a series of latitudinal 'hotspots' (Helmuth *et al.* 2002, Hobday *et al.* 2006).

7. The central-eastern and south-eastern coast of Australia, including NSW, has been identified as being particularly vulnerable to climate change (Poloczanska *et al.* 2007, Ridgway 2007). The dominant oceanographic feature of this region is the East Australian Current (EAC), a warm western boundary current that flows southward along the coast (Ridgway & Dunn 2003). In the past 60 years the EAC has strengthened in flow, resulting in warmer water and associated anticyclonic eddy systems travelling further southward (Ridgway 2007). Impacts on native biodiversity and threatened species in NSW waters will be linked to such changes in the EAC. Extensions in the distribution and range of warmer water species are predicted, along with retractions in the distribution and range of cooler water species (Fairweather & Cowie 2007).

8. In NSW, shifts in climate are predicted to negatively affect local endemic aquatic species, particularly those with restricted habitats and geographic distributions, and a proportion of these may become locally extinct (O'Hara 2002, Hughes 2003, Ponder 2004). Already there is documentation that shows the distribution of three iconic brown algae have retracted to the south along the NSW coastline as sea surface water temperatures have risen over the past 70-90 years. These brown algae have gametes that are environmentally sensitive and may not survive long enough to produce zygotes and thus not germinate to continue recruitment of macrophytic sporophytes. *Durvillaea potatorum* was known to be common on the rocky shore of Bermagui yet is now known from Tathra south (Millar 2007). *Ecklonia radiata* has retracted from Caloundra to Byron Bay (Millar 2007), and *Hormosira banksii* from Caloundra to Ballina. *Hormosira banksii* has also become locally extinct on Lord Howe Island where it was an abundant intertidal species in the 1920s. Invertebrate species such as the critically endangered marine slug, *Smeagol hilaris*, may also be further threatened due to their limited geographic distribution.

9. Seagrasses are very likely to be negatively impacted by climate change, particularly changes in sea level (Short and Neckles 1999, Duarte 2002). The current distribution and abundance of seagrass species in the NSW water-bodies is a result of the interaction of many environmental factors, particularly the underwater light climate. This underwater light climate is primarily a function of depth, and any changes in the water level of estuaries and coastal lakes would result in changes in the distribution of seagrasses, particularly at the lower depth margins (Ralph *et al.* 2007). The nature of the long-term changes of seagrass distribution and abundances under changing climate conditions is likely to be negative, but is difficult to predict. It will depend on the individual physical and environmental characteristics at particular locations, and the ability of seagrasses to respond to any change that occurs, which is largely unknown (Short and Neckles 1999).

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10. Climate change is also predicted to have an impact on freshwater communities through the changes in the seasonality of rainfall (increases and decreases) and the frequency and severity of storm events. Annually, the numbers of extreme warm events is likely to increase. The regional scenario for NSW freshwater aquatic systems, is for drying of aquatic areas, increased drought occurrence, higher water temperatures with diminished water flows, which will produce low oxygen levels and increased conductivity (salinity) (Hennessy *et al.* 2007). Freshwater communities of fish and invertebrates in rivers, swamps and floodplains are likely to experience additional impacts as most species have specialised habitat and dietary requirements (Ficke and Myrick 2004). Compared to the open estuaries and ocean waters, freshwater rivers are geographically constrained and limit the migratory options for aquatic plants, invertebrates and fish. Freshwater flows are a stimulus for breeding in many Australian freshwater fish species (Geddes and Puckeridge 1989) and thus the changes in volume and timing of spring floods are predicted to significantly impact fish recruitment (Burchmore 1990). With low or reduced flow, freshwater river systems will shift towards lotic rather than lentic environments with a corresponding shift in the biological communities. In shallow freshwater rivers and lakes there is a balance between the phytoplankton communities (heterotrophy) and the bacterial biofilm (mostly autotrophs) on the substrate as the primary producers. Under some climate change scenarios a metabolic shift from heterotrophic communities to autotrophic communities is predicted (Freeman *et al.* 1994).

11. Shifts in the distribution of non-indigenous species, and the introduction of new invasive species to NSW waters, are likely to cause native species, populations and ecological communities that are not currently threatened to become threatened, and those that are currently threatened to be deleteriously affected. The impact of climate change on non-indigenous fish and marine vegetation in NSW waters is unclear. Although the impact of some non-indigenous species may diminish, such as freshwater carp whose spawning opportunities on floodplains may decrease with rising temperatures (Fairweather & Cowie 2007), others are likely to increase. For example, the distribution of the invasive alga *Caulerpa taxifolia* may increase due to more-suitable conditions in estuaries (Creese *et al.* 2004).

12. Human-caused climate change is predicted to impact negatively on the survival and demography of aquatic ecosystems in NSW. Changing flows of freshwater and predicted upstream migration of saltwater in NSW's rivers and estuaries are predicted to alter aquatic habitats and change the distribution of aquatic flora and fauna (Fairweather & Cowie 2007). Estuarine areas currently suitable for oyster culture and prawns may change, thus affecting associated fisheries (Hobday *et al.* 2006, Fairweather & Cowie 2007). Ocean warming, an increase in the number of extreme hot weather events, and increased flooding may drive distributions of seagrass and kelp species southwards, thus increasing their risk of extirpation and extinction (Okey *et al.* 2006, Poloczanska 2006). Similar southward contractions are expected for species associated with intertidal rocky shores, with evidence of such shifts already apparent from rocky shores in the UK, Ireland, USA and Chile (Barry *et al.* 1995, Sagarin *et al.* 1999, Mieszkowska *et al.* 2005, Rivadeneira & Fernandez 2005, Poloczanska & Babcock 2006). Changes in primary production in the water column may affect the demography of soft sediment fauna by reducing food sources (Okey 2006). Such changes in biological communities may affect on the physical characteristics of the soft sediment, possibly influencing its stability (Poloczanska *et al.* 2007). Many benthic, demersal and pelagic fish species are shifting their ranges poleward in response to

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Phone: (02)4982-1232 Fax: (02)4982-1107 Email:fsc@industry.nsw.gov.au

climate-related changes, thus affecting the composition of their communities, and ecosystem functioning in general (Hobday 2006, Okey & Hobday 2006).

13. Of particular concern are the effects of ocean acidification (due to changes in water chemistry) to aquatic life in NSW waters. The severity of impacts resulting from ocean acidification has been reported globally, and the complexity of responses by species and ecosystems, and the rapid rate at which it is occurring, is alarming (Caldeira & Wickett 2005, Harley *et al.* 2006, Fabry *et al.* 2008). Increasing acidity has the potential to affect all estuarine and marine organisms either directly or through flow-on effects in food webs (Monaco Declaration 2008). Based on current projections, ocean acidification is predicted to tip the balance between calcification and erosion for organisms that use calcium carbonate to build and maintain shells, carapaces and skeletons. At particular risk are slow growing deep-sea and cold-water corals in NSW waters, such as *Madrepora oculata*, which are expected to reduce in distribution as the aragonite saturation horizon shallows (Poloczanska & Butler 2006, Poloczanska *et al.* 2007), along with most molluscs, echinoderms, crustaceans, and coralline algae (Hobday *et al*. 2006, Fabry *et al.* 2008). Physiological and developmental processes of many species, particularly in early life-history stages, may also be severely impaired by ocean acidification and the magnitudes of the changes are of acute concern. For example, a recent study on the sea urchin *Heliocidaris erythrogramma*, an ecologically important species for inshore waters in NSW, reported a 25% reduction in fertilisation success in response to conservative levels of CO_2-induced acidification predicted for the year 2100 (Havenhand *et al.* 2008).

14. In view of the above, the Fisheries Scientific Committee is of the opinion that Human-Caused Climate Change adversely affects threatened species and could cause species, populations or ecological communities that are not threatened to become threatened. Therefore, this process qualifies for inclusion in Schedule 6 of the *Fisheries Management Act 1994* as a KEY THREATENING PROCESS.

Sources and Links

Barry, J.P., Baxter, C.H., Sagarin, R.D. and Gilman, S.E. (1995). Climate-related, long-term faunal changes in a California rocky intertidal community. *Science* 267: 672-675.

Burchmore, J.J. (1990). Implications of the Greenhouse effect for native freshwater fishes in New South Wales. *Wetlands* 10: 30-32.

Caldeira, K. and Wickett, M.E. (2005). Ocean model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and ocean. *Journal of Geophysical Research – Oceans* 110, doi: 10.1029/2004JC002671.

Creese, R.G., Davis, A.R. and Glasby, T.M. (2004). Eradicating and preventing the spread of the invasive alga *Caulerpa taxifolia* in NSW. NSW Fisheries Final Report Series No 64: ISSN 1440-3544.

Duarte, C.M. (2002). The future of seagrass meadows. *Environmental Conservation* 29: 192-206.

Port Stephens Fisheries Institute, Locked Bag 1, Nelson Bay NSW 2315
Phone: (02)4982-1232 Fax: (02)4982-1107 Email:fsc@industry.nsw.gov.au

Fabry, V.J., Siebel, B.A., Feely, R.A. and Orr, J.C. (2008). Impacts of ocean acidification on marine fauna and ecosystem processes. *ICES Journal of Marine Science* 65: 414-432.

Fairweather, H. and Cowie, A. (2007). *Climate Change Research Priorities for NSW Primary Industries*, Discussion paper prepared by NSW DPI for the Ministerial Advisory Council on Primary Industries Science, NSW Department of Primary Industries, Australia. October 2005.

Ficke, A.A., Myrick, C.A. and Hansen, L.J. (2007). Potential impacts of global climate change on freshwater fisheries. *Reviews in Fish Biology and Fisheries* 17: 581-613.

Freeman, C., Gresswell, R., Guasch, H., Hudson, J., Lack, M., Reynolds, B., Sabater, F. and Sabater, S. (1994). The role of drought in the impact of climatic-change on the microbiota of peatland streams. *Freshwater Biology* 32: 223-230.

Geddes, M.C. and Puckeridge, J.T. (1989). Survival and growth of larval and juvenile native fish – the importance of the floodplain. Murray-Darling Basin Commission, Canberra, Australia.

Harley, C.D.G., Hughes, A.R., Hultgren, K.M., Miner, B.G., Sorte, C.J.B., Thornber, C.S., Rodriguez, L.F., Tomanek, L. and Williams, S.L. (2006). The impacts of climate change in coastal marine systems. *Ecology Letters* 9: 228-241.

Havenhand, J.N., Buttler, F-R., Thorndyke, M.C. and Williamson, J.E. (2008). Near-future levels of ocean acidification reduce fertilization success in a sea urchin. *Current Biology* 18: R651-R652.

Helmuth, B., Harley, C.D.G., Halpin, P.M., O'Donnell, M., Hofmann, G.E. and Blanchette, C.A. (2002). Climate change and latitudinal patterns of intertidal thermal stress. *Science* 298: 1015-1017.

Hennessy, K., Fitzharris, B., Bates, B.C., Harvey, N., Howden, S.M., Hughes, L., Salinger, J. and Warwick, R. (2007). Australia and New Zealand. Pages 507-540 *in* Parry ML *et al.* eds, *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Hijmans, R.J. and Graham, C.H. (2006). The ability of climate envelope models to predict the effect of climate change on species distributions. *Global Change Biology* 12: 2272-2281.

Hobday, A.J. (2006). Impacts of climate change on pelagic fishes. Pages 94-101 *in* Hobday AJ *et al.* eds, *Impacts of Climate Change on Australian Marine Life: Part C. Literature Review*, Report to the Australian Greenhouse Office, Canberra, Australia, September 2006.

Hobday, A.J. and Matear, R. (eds, 2005). *Review of the Climate Impacts on Australian Fisheries and Aquaculture: Implications for the Effects of Change*, Report to the Australian Greenhouse Office, Canberra, Australia. December 2005.

Port Stephens Fisheries Institute, Locked Bag 1, Nelson Bay NSW 2315
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Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. and Richardson, A.J. (eds, 2006). *Impacts of Climate Change on Australian Marine Life*, Report to the Australian Greenhouse Office, Canberra, Australia. September 2006.

Hofmann, D.J., Butler, J.H., Dlugokencky, E.J., Elkins, J.W., Masarie, K., Montzka, S.A. and Tans, P. (2006). The role of carbon dioxide in climate forcing from 1979 to 2004: introduction of the Annual Greenhouse Gas Index. *Tellus B* 58: 614-619.

Hughes, L. (2000). Biological consequences of global warming: is the signal already apparent across natural systems? *Trends in Ecology and Evolution* 20: 380-386.

Hughes, L. (2003). Climate change and Australia: trends, projections and impacts. *Austral Ecology* 28: 423-443.

Hughes, L. and Westoby, M. (1994). Climate change and conservation policies in Australia: coping with change that is far away and yet not certain. *Pacific Conservation Biology* 1: 308-318.

Kurschner, W.M., Kvacek, Z. and Dilcher, D.L. (2008). The impact of Miocene atmospheric carbon dioxide fluctuations on climate and the evolution of terrestrial ecosystems. *Proceedings of the National Academy of Science* 105: 449-453.

Ling, S.D., Johnson, C.R., Ridgway, K., Hobday, A.J. and Haddon, M. (2009). Climate-driven range extension of a sea urchin: inferring future trends by analysis of recent population dynamics. *Global Change Biology* 15: 719-731.

Meehl, G.A., Stocker, T.F. and Collins, W.D. (2007). Global climate projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds Solomon S, Qin D, Manning M *et al.*), Cambridge University Press, Cambridge, UK and New York, NY, USA.

Mieszkowska, N., Leaper, R., Moore, P., Kendall, M.A., Burrows, M.T., Lear, D., Poloczanska, E.S., Hiscock, K., Moschella, P.S., Thompson, R.C., Herbert, R.J., Laffoley, D., Baxter, J., Southward, A.J. and Hawkins, S.J. (2005). *Assessing and Predicting the Influence of Climate Change using Intertidal Rocky Shore Biota*, Marine Biological Association of the UK, Plymouth, UK.

Millar, A.J.K. (2007). The Flindersian and Peronian Provinces. Pages 554-559 In: McCarthy PM & Orchard AE eds, *Algae of Australia*, Australian Biological Resources Study, CSIRO Publishing, Collingwood, Victoria, Australia.

Monaco Declaration. (2008). *Second International Symposium on the Ocean in a High-CO_2 World*, Monaco, October 2008.

O'Hara, T.D. (2002). Endemism, rarity and vulnerability of marine species along a temperate coastline. *Invertebrate Systematics* 16: 671-684

Okey, T.A., Engstrom, N. and Babcock, R. (2006). Impacts of climate change on kelp. Pages 53-58 *in* Hobday AJ *et al.* eds, *Impacts of Climate Change on Australian Marine*

Port Stephens Fisheries Institute, Locked Bag 1, Nelson Bay NSW 2315
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Life: Part C. Literature Review, Report to the Australian Greenhouse Office, Canberra, Australia, September 2006.

Okey, T.A. and Hobday, A.J. (2006). Impacts of climate change on benthic and demersal fishes. Pages 88-93 *in* Hobday AJ *et al.* eds, *Impacts of Climate Change on Australian Marine Life: Part C. Literature Review*, Report to the Australian Greenhouse Office, Canberra, Australia, September 2006.

Pagani, M., Zachos, J.C., Freeman, K.H., Tipple, B. and Bohaty, S. (2005). Marked decline in atmospheric carbon dioxide concentrations during the Palaeogene. *Science* 309: 600-603.

Poloczanska, E.S. (2006). Impacts of climate change on seagrasses. Pages 27-35 *in* Hobday AJ *et al.* eds, *Impacts of Climate Change on Australian Marine Life: Part C. Literature Review*, Report to the Australian Greenhouse Office, Canberra, Australia, September 2006.

Poloczanska, E.S. and Babcock, R. (2006). Impacts of climate change on rocky shores. Pages 53-58 *in* Hobday AJ *et al.* eds, *Impacts of Climate Change on Australian Marine Life: Part C. Literature Review*, Report to the Australian Greenhouse Office, Canberra, Australia, September 2006.

Poloczanska, E.S., Babcock, R.C., Butler, A., Hobday, A., Hoegh-Guldberg, O., Kunz, T.J., Matear, R., Milton, D.A., Okey, T.A. and Richardson, A.J. (2007). Climate change and Australian marine life. *Oceanography and Marine Biology: An Annual Review* 45: 409-480.

Poloczanska, E.S. and Butler, A. (2006). Impacts of climate change on deep-sea and cold-water corals. Pages 69-76 *in* Hobday AJ *et al.* eds, *Impacts of Climate Change on Australian Marine Life: Part C. Literature Review*, Report to the Australian Greenhouse Office, Canberra, Australia, September 2006.

Ponder, W.F. (2004). Narrow range endemism in the sea and its implications for conservation. *Australian Zoologist*. pp. 89–102. In *Conserving Marine Environments* (ed Hutchings P, Lunney D), Royal Zoological Society of NSW, Mosman.

Ralph, P.J., Durako, M.J., Enriquez, S., Collier, C.J. and Doblin, M.A. (2007). Impact of light limitation on seagrasses. *Journal of Experimental Marine Biology and Ecology* 350: 176-193.

Ridgway, K.R., Dunn, J.R. (2003). Mesoscale structure of the mean East Australian Current system and its relationship with topography. *Progress in Oceanography* 56: 189-222.

Ridgway, K.R. (2007). Long-term trend and decadal variability of the southward penetration of the East Australian Current. *Geophysical Research Letters* L13613, doi: 10.1029/2007GL030393.

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Rivadeneira, M.M. and Fernandez, M. (2005). Shifts in southern endpoints of distribution in rocky intertidal species along the south-eastern Pacific coast. *Journal of Biogeography* 32: 203-209.

Sagarin, R.D., Barry, J.P., Gilman, S.E. and Baxter, C.H. (1999). Climate-related change in an intertidal community over short and long time scales. *Ecological Monographs* 69: 465-490.

Short, F.T. and Neckles, H.A. (1999). The effects of global climate change on seagrasses. *Aquatic Botany* 63: 169-196.

Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, M., Hoegh-Guldberg, O. and Bairlein, F. (2002). Ecological responses to recent climate change. *Nature* 416: 389-395.

Wespestad, V., Fritz, L.W., Ingraham, J.W. and Megrey, B.A. (2000). On the relationship between cannibalism, climate variability, physical transport, and recruitment of the Bering sea walleye Pollock (*Theragra chalcogramma*). *ICES Journal of Marine Science* 57: 272-278.

Assoc Prof Ron West
Chairperson
Fisheries Scientific Committee

Port Stephens Fisheries Institute, Locked Bag 1, Nelson Bay NSW 2315
Phone: (02)4982-1232 Fax: (02)4982-1107 Email:fsc@industry.nsw.gov.au