Marine and Freshwater Research 2019, **70**, 62–70.
http://dx.doi.org/10.1071/MF17330_AC

Supplementary material

National research planning accelerates relevance and immediacy of climate-adaptation science

Scott D. Ling[A,D] *and Alistair J. Hobday*[B,C]

[A]Ecology & Biodiversity Centre, Institute for Marine & Antarctic Studies, University of Tasmania, Hobart, Tas. 7000, Australia.

[B]CSIRO Oceans and Atmosphere, Hobart, Tas. 7000, Australia.

[C]Centre for Marine Socioecology, University of Tasmania, Hobart, Tas. 7000, Australia.

[D]Corresponding author. Email: scott.ling@utas.edu.au

Table S1. The priority Marine National Adaptation Research Plan questions (Holbrook *et al*. 2012)

Sector	Question	Code
Aquaculture	1.1. Which farmed species in which locations are most likely to be impacted as a result of climate change?	1.1
	1.2. What are the most likely effects of climate change on key environmental variables affecting aquaculture operations, including ocean temperature, stratification and oxygenation, freshwater runoff or availability, and extreme wind and wave events and which regions are most vulnerable to such changes?	1.2
	1.3. What are likely policy changes driven by climate change that will affect aquaculture businesses either directly through changes in access to suitable locations, and natural resources such as freshwater or marine-based feeds or indirectly because of changes in harvest marine policies, affecting feed supplies or non-marine climate adaptation and mitigation policies?	1.3
	1.4. Which local or regional communities or economies are most dependent on aquaculture businesses and how will changes in aquaculture production (especially decline in activity) affect those vulnerable communities socially and economically?	1.4
	1.5. What options are there for businesses to adapt to climate change effects either by minimising adverse impacts or taking advantage of opportunities, including through selective breeding, changing or diversifying farmed species, relocating, expanding or contracting business sites or improving environmental control through infrastructure development? What are the barriers to implementing such changes and how might they be overcome?	1.5
	1.6. What significant changes in aquaculture have already occurred because of extrinsic factors and what can be learned from those changes that will inform adaptation to climate change?	1.6
Fisheries	2.1. Which fishery stocks, in which locations, are most likely to change as a result of climate change? What will those changes be (e.g. in distribution, productivity) and when are they likely to appear under alternative climate change scenarios?	2.1
	2.2. What and where are the most likely effects of climate change on key variables affecting fishery access, including wind and wave climatologies and boating access?	2.2
	2.3. Which local or regional communities or economies, if any, are dependent on commercial or recreational fishing? How will changes in fisheries (especially decline in activity) affect those vulnerable communities socially and economically?	2.3
	2.4. What are the likely policy changes driven by climate change that will affect commercial fisheries either directly through changes in harvest policies or indirectly because of changes in non-harvest marine policies or changes in non-marine climate adaptation or mitigation policies?	2.4
	2.5. What options or opportunities are there for commercial fishers in identified vulnerable fisheries to adapt to climate change effects through changing target species, capture methods and management regime, or industry diversification, relocation or divestment?	2.5
	2.6. What options or opportunities exist or might become available for recreational fishers in identified vulnerable fisheries to adapt to climate change effects through changing target species or preferred fishing method or travelling to pursue their preferred target species or method?	2.6
	2.7. How have enablers been used and barriers to adaptation been overcome? What significant changes in fisheries have occurred before because of extrinsic factors and what can be learned from those changes that will inform adaptation to climate change?	2.7
Conservation	3.1. Which ecosystems and species of conservation priority most require adaptation management and supporting research, based on their status, value, vulnerability to climate change and the feasibility of adaptive responses?	3.1
	3.2. What are the critical thresholds to ecosystem change and how close is the ecosystem to such 'tipping points'? How can we improve our measurement of marine ecosystems to account for ecosystem dynamics and processes?	3.2
	3.3. How will goals and governance for conservation of Australia's marine biodiversity need to change to adapt to climate change impacts? What are the barriers, limits and costs to implementing adaptation and effective policy responses to climate change?	3.3
	3.4. How should conservation managers and planners adapt their practices to ameliorate climate change risks and enhance adaptation options? What intervention strategies will increase system resilience and improve the time within which biological systems can adjust to a future climate?	3.4
Tourism	4.1. What are the predicted regional impacts of climate change for marine tourism assets (i.e. what tourism sites will be most vulnerable to change and to what degree?)	4.1
	4.2. How can the impacts on tourism, if any, of public perceptions of climate impacts on Australia's marine biodiversity and resources be minimised?	4.2
	4.3. How can the links between resource condition and marine-dependent tourism business vitality be modelled and evaluated?	4.3
	4.4. What is the adaptive capacity of the marine tourism industry and how can it be enhanced to cope with climate change impacts?	4.4
	4.5. What social, ecosystem-based, engineering and technical approaches might reduce risks to marine tourism infrastructure from increased weather severity	4.5

Sector	Question	Code
	4.6 Are current safety standards and protocols for marine activities adequate to deal with future conditions under climate change?	4.6
	4.7. What are the most appropriate techniques for preserving beaches in the face of rising sea levels?	4.7
Cross-cutting	5.1. What are the key interactions across sectors, cumulative impacts and cross-jurisdictional issues that will affect the development of adaptation strategies in each sector and how can these cross- and multi-sectoral issues best be addressed?	5.1
	5.2. What are the most appropriate techniques for preserving estuarine systems in the face of climate change?	5.2
	5.3. How can land-based climate change adaptation decisions be developed and implemented to also support adaptation for marine water quality and marine resources and biodiversity, including aquaculture, fisheries, conservation and tourism, taking account of multiple stressors, the cumulative pressures of co-occurring factors and flow-on effects for industries and ecosystem health?	5.3
	5.4. What are the long-term consequences of ocean acidification, particularly for acclimatisation or adaptation of marine organisms and ecosystems, and what adaptation options are available to the managers of marine biodiversity and resources?	5.4
	5.5. How can mitigation initiatives in marine environments, such as carbon sequestration initiatives in coastal or marine areas, contribute to adaptation outcomes?	5.5
	5.6. How can climate change-induced changes to the distribution and effect of marine diseases, predators, pests and other problem organisms be managed?	5.6
	5.7. What are the major sources of social resilience, and the processes by which stakeholders and organisations interact, negotiate, and build alliances? What roles do varying perceptions among stakeholders play in adaptive management and how do they change over time?	5.7

http://dx.doi.org/10.1071/MF17330_AC

Table S2. Alphabetically listed search terms used for Web of Science (WoS) database search for research papers examining climate change in Australia across marine sectors

For search-term hierarchy, see Table S3. Efficacy of structured searching was also examined. For efficiency of the structured WoS search, we compared our structured search to the semi-structured journal and author search by Holbrook and Johnson (2014) who reviewed Australian marine resources and biodiversity climate-change literature for the period 2009–2011. Over the same period, the Holbrook and Johnson (2014) literature search returned 174 articles. Eliminating grey literature (which our method did not cover) and general studies not related to Australia resulted in a total of 77 papers from Holbrook and Johnson (2014). Our structured WoS search identified 57 (i.e. missed 20) of these 77 papers (74% success). However, on the basis of WoS searches using the author, title and keywords for these 20 missing papers, we could not locate 14 of these, indicating that they were not indexed in WoS. Eliminating these 14 papers (i.e. 77 – 14 = 63 papers), we failed to locate only six papers, being a success rate of 90.5%. Thus, we consider that our systematic and repeatable WOS search located 74–90.5% of the relevant literature in Holbrook and Johnson (2014). Conversely, our WoS search located a total of 123 papers for this time period; thus, the semi-structured approach of Holbrook and Johnson (2014) missed 46 papers in our set (37.4%, 123 – 77 = 46). If our search that yielded 123 papers represented 74–90.5% of the literature, then the complete Australian literature in the period 2009–2011 is between 136 and 166 papers. Although we cannot test our sampling approach for the second period of time (2012–2015), assuming the same search efficiency, our full sample should be suitably robust for analysis of trends

Number	Search term
1	Acidification
2	Adaptation
3	Aquaculture
4	**Australia**
5	Carbon sequestration
6	Climate
7	**Climate change**
8	Fisheries
9	Future
10	Infrastructure
11	**Marine**
12	Ocean
13	Range shift
14	Range-extender
15	Range extension
16	Resilience
17	Risk
18	Seafood
19	Shift
20	Species
21	Tourism
22	Tropicalisation
23	Vulnerability
24	Vulnerable
25	Warming

Table S3. Hierarchy of search terms used for literature review of all Web-of-Science databases for time period 1 January 2009 to 31 December 2015

For example, Search 1 used the words ‘Australia’ and ‘climate change’ and ‘marine’

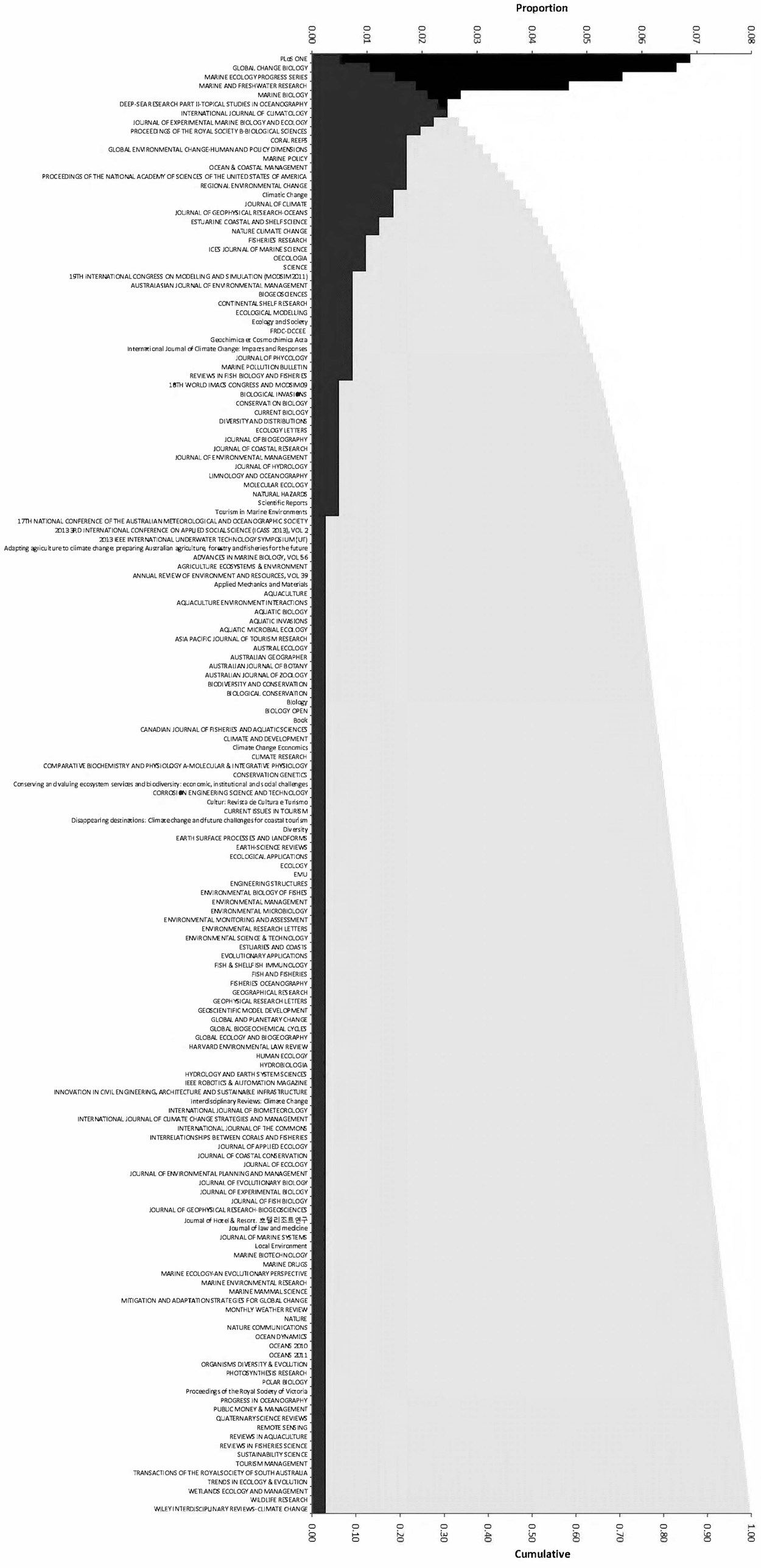
Search number	Records	Term 1		Term 2		Term 3		Term 4		Term 5		Term 6		Term 7		Term 8		Term 9		Term 10		Term 11
1	616	Australia	AND	Climate change	AND	Marine																
2	2006	Australia	AND	Marine	AND	Climate change	OR	Climate-driven	OR	Range shift	OR	Range extension	OR	Range-extender	AND	Aquaculture	AND	Fisheries	AND	Conservation	AND	Tourism
3	45	Australia	AND	Marine	AND	Climate change	AND	Adaptation														
4	6	Australia	AND	Ocean	AND	Warming	AND	Aquaculture														
5	30	Australia	AND	Ocean	AND	Warming	AND	Fisheries														
6	5	Australia	AND	Ocean	AND	Warming	AND	Infrastructure														
7	5	Australia	AND	Ocean	AND	Warming	AND	Tourism														
8	68	Australia	AND	Marine	AND	Climate	AND	Risk														
9	142	Australia	AND	Marine	AND	Species	AND	Shift														
10	132	Australia	AND	Ocean	AND	Acidification																
11	93	Australia	AND	Marine	AND	Adaptation																
12	7	Australia	AND	Marine	AND	Carbon sequestration																
13	353	Australia	AND	Future	AND	Ocean																
14	4	Australia	AND	Climate	AND	Seafood																
15	299	Australia	AND	Climate	AND	Vulnerable																
16	360	Australia	AND	Climate	AND	Vulnerability																
17	21	Marine	AND	Climate change	AND	Tropicalisation	OR	Resilience														
Total	4192																					

Table S4. Breadth of study-type categories used to score each publication

Category	Subcategory
Study type	Laboratory
	Field
	Model
	Review
	Methods or frameworks
	Meta-analysis
Region	Australian
	International
Bioregion	Temperate
	Tropical
Climate-change stressor	Ocean acidification
	Warming
	Circulation
	Sea level
	Weather system
	Other anthropogenic stressor
Natural habitat (directly studied or considered)	Reef
	Soft sediment
	Pelagic
	Estuarine
	Wetlands
	Saltmarshes
	Deep sea
	Beaches
	Caves
Taxon (directly studied or considered)	Humans
	Mammals
	Seabirds
	Reptile
	Fish
	Invertebrate (non-coral)
	Corals
	Macroalgae
	Seagrass
	Mangroves
	Other marine plants
	Phyoplankton
	Zooplankton
	Microbes
	Forams
	Pteropods
	Ascidians
Life-history stage	Embryos
	Larval
	Juv
	Adult

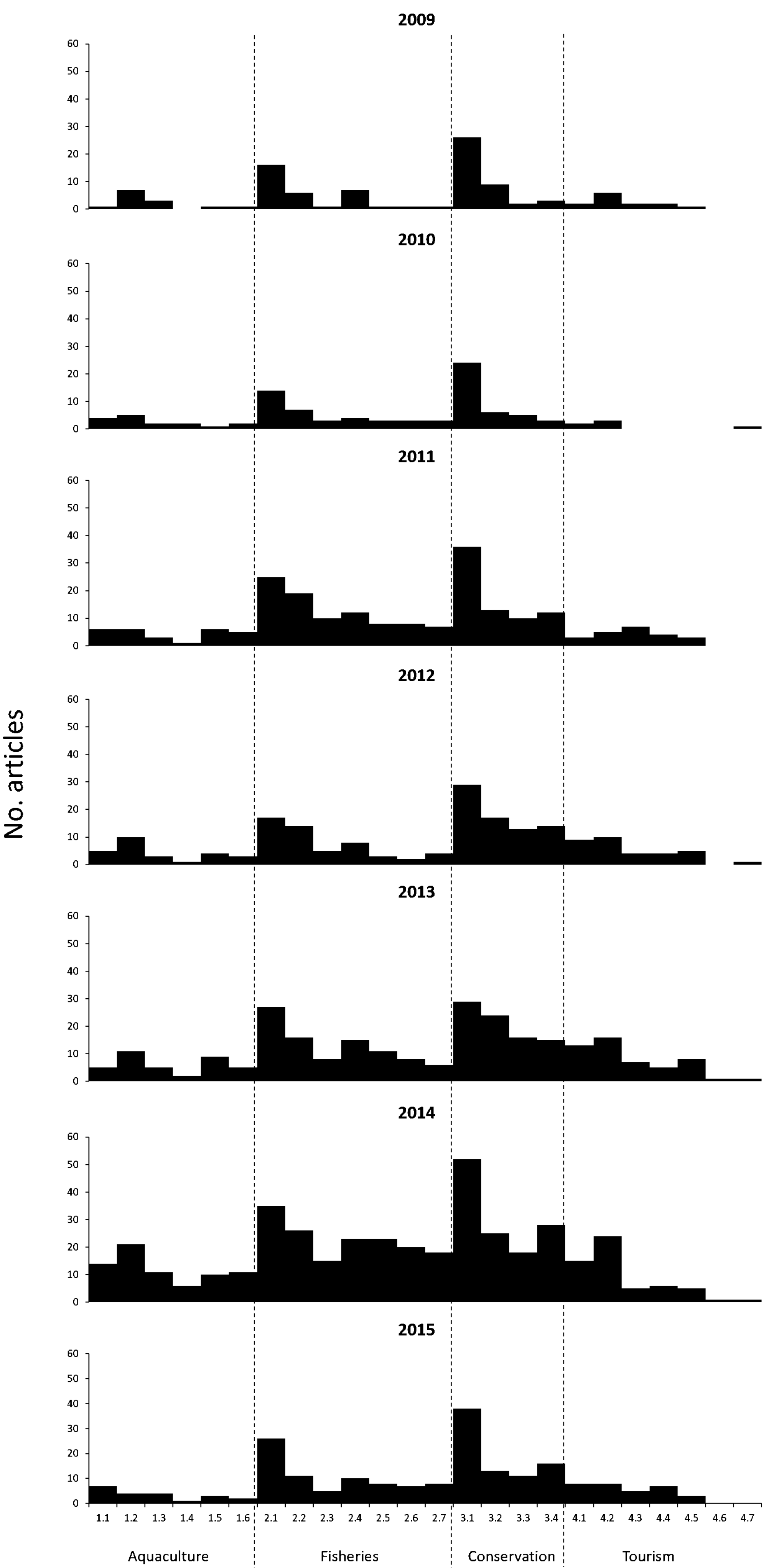
http://dx.doi.org/10.1071/MF17330_AC

Fig. S1. Rank proportional and cumulative contributions of different journals to publications, on the basis of 404 returned articles following Web of Science (WoS) search focussed on Australian marine climate change for the period of 2009–2015. (See following page.)


Proportion
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
PLoS ONE
GLOBAL CHANGE BIOLOGY
MARINE ECOLOGY PROGRESS SERIES
MARINE AND FRESHWATER RESEARCH
MARINE BIOLOGY
DEEP-SEA RESEARCH PART II-TOPICAL STUDIES IN OCEANOGRAPHY
INTERNATIONAL JOURNAL OF CLIMATOLOGY
JOURNAL OF EXPERIMENTAL MARINE BIOLOGY AND ECOLOGY
PROCEEDINGS OF THE ROYAL SOCIETY B-BIOLOGICAL SCIENCES
CORAL REEFS
GLOBAL ENVIRONMENTAL CHANGE-HUMAN AND POLICY DIMENSIONS
MARINE POLICY
OCEAN & COASTAL MANAGEMENT
PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA
REGIONAL ENVIRONMENTAL CHANGE
Climatic Change
JOURNAL OF CLIMATE
JOURNAL OF GEOPHYSICAL RESEARCH-OCEANS
ESTUARINE COASTAL AND SHELF SCIENCE
NATURE CLIMATE CHANGE
FISHERIES RESEARCH
ICES JOURNAL OF MARINE SCIENCE
OECOLOGIA
SCIENCE
19TH INTERNATIONAL CONGRESS ON MODELLING AND SIMULATION (MODSIM2011)
AUSTRALASIAN JOURNAL OF ENVIRONMENTAL MANAGEMENT
BIOGEOSCIENCES
CONTINENTAL SHELF RESEARCH
ECOLOGICAL MODELLING
Ecology and Society
FRDC-DCCEE
Geochimica et Cosmochimica Acta
International Journal of Climate Change: Impacts and Responses
JOURNAL OF PHYCOLOGY
MARINE POLLUTION BULLETIN
REVIEWS IN FISH BIOLOGY AND FISHERIES
18TH WORLD IMACS CONGRESS AND MODSIM09
BIOLOGICAL INVASIONS
CONSERVATION BIOLOGY
CURRENT BIOLOGY
DIVERSITY AND DISTRIBUTIONS
ECOLOGY LETTERS
JOURNAL OF BIOGEOGRAPHY
JOURNAL OF COASTAL RESEARCH
JOURNAL OF ENVIRONMENTAL MANAGEMENT
JOURNAL OF HYDROLOGY
LIMNOLOGY AND OCEANOGRAPHY
MOLECULAR ECOLOGY
NATURAL HAZARDS
Scientific Reports
Tourism in Marine Environments
17TH NATIONAL CONFERENCE OF THE AUSTRALIAN METEOROLOGICAL AND OCEANOGRAPHIC SOCIETY
2013 3RD INTERNATIONAL CONFERENCE ON APPLIED SOCIAL SCIENCE (ICASS 2013), VOL 2
2013 IEEE INTERNATIONAL UNDERWATER TECHNOLOGY SYMPOSIUM (UT)
Adapting agriculture to climate change: preparing Australian agriculture, forestry and fisheries for the future
ADVANCES IN MARINE BIOLOGY, VOL 56
AGRICULTURE ECOSYSTEMS & ENVIRONMENT
ANNUAL REVIEW OF ENVIRONMENT AND RESOURCES, VOL 39
Applied Mechanics and Materials
AQUACULTURE
AQUACULTURE ENVIRONMENT INTERACTIONS
AQUATIC BIOLOGY
AQUATIC INVASIONS
AQUATIC MICROBIAL ECOLOGY
ASIA PACIFIC JOURNAL OF TOURISM RESEARCH
AUSTRAL ECOLOGY
AUSTRALIAN GEOGRAPHER
AUSTRALIAN JOURNAL OF BOTANY
AUSTRALIAN JOURNAL OF ZOOLOGY
BIODIVERSITY AND CONSERVATION
BIOLOGICAL CONSERVATION
Biology
BIOLOGY OPEN
Book
CANADIAN JOURNAL OF FISHERIES AND AQUATIC SCIENCES
CLIMATE AND DEVELOPMENT
Climate Change Economics
CLIMATE RESEARCH
COMPARATIVE BIOCHEMISTRY AND PHYSIOLOGY A-MOLECULAR & INTEGRATIVE PHYSIOLOGY
CONSERVATION GENETICS
Conserving and valuing ecosystem services and biodiversity: economic, institutional and social challenges
CORROSION ENGINEERING SCIENCE AND TECHNOLOGY
Cultur: Revista de Cultura e Turismo
CURRENT ISSUES IN TOURISM
Disappearing destinations: Climate change and future challenges for coastal tourism
Diversity
EARTH SURFACE PROCESSES AND LANDFORMS
EARTH-SCIENCE REVIEWS
ECOLOGICAL APPLICATIONS
ECOLOGY
EMU
ENGINEERING STRUCTURES
ENVIRONMENTAL BIOLOGY OF FISHES
ENVIRONMENTAL MANAGEMENT
ENVIRONMENTAL MICROBIOLOGY
ENVIRONMENTAL MONITORING AND ASSESSMENT
ENVIRONMENTAL RESEARCH LETTERS
ENVIRONMENTAL SCIENCE & TECHNOLOGY
ESTUARIES AND COASTS
EVOLUTIONARY APPLICATIONS
FISH & SHELLFISH IMMUNOLOGY
FISH AND FISHERIES
FISHERIES OCEANOGRAPHY
GEOGRAPHICAL RESEARCH
GEOPHYSICAL RESEARCH LETTERS
GEOSCIENTIFIC MODEL DEVELOPMENT
GLOBAL AND PLANETARY CHANGE
GLOBAL BIOGEOCHEMICAL CYCLES
GLOBAL ECOLOGY AND BIOGEOGRAPHY
HARVARD ENVIRONMENTAL LAW REVIEW
HUMAN ECOLOGY
HYDROBIOLOGIA
HYDROLOGY AND EARTH SYSTEM SCIENCES
IEEE ROBOTICS & AUTOMATION MAGAZINE
INNOVATION IN CIVIL ENGINEERING, ARCHITECTURE AND SUSTAINABLE INFRASTRUCTURE
Interdisciplinary Reviews: Climate Change
INTERNATIONAL JOURNAL OF BIOMETEOROLOGY
INTERNATIONAL JOURNAL OF CLIMATE CHANGE STRATEGIES AND MANAGEMENT
INTERNATIONAL JOURNAL OF THE COMMONS
INTERRELATIONSHIPS BETWEEN CORALS AND FISHERIES
JOURNAL OF APPLIED ECOLOGY
JOURNAL OF COASTAL CONSERVATION
JOURNAL OF ECOLOGY
JOURNAL OF ENVIRONMENTAL PLANNING AND MANAGEMENT
JOURNAL OF EVOLUTIONARY BIOLOGY
JOURNAL OF EXPERIMENTAL BIOLOGY
JOURNAL OF FISH BIOLOGY
JOURNAL OF GEOPHYSICAL RESEARCH-BIOGEOSCIENCES
Journal of Hotel & Resort, 호텔리조트연구
Journal of law and medicine
JOURNAL OF MARINE SYSTEMS
Local Environment
MARINE BIOTECHNOLOGY
MARINE DRUGS
MARINE ECOLOGY-AN EVOLUTIONARY PERSPECTIVE
MARINE ENVIRONMENTAL RESEARCH
MARINE MAMMAL SCIENCE
MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE
MONTHLY WEATHER REVIEW
NATURE
NATURE COMMUNICATIONS
OCEAN DYNAMICS
OCEANS 2010
OCEANS 2011
ORGANISMS DIVERSITY & EVOLUTION
PHOTOSYNTHESIS RESEARCH
POLAR BIOLOGY
Proceedings of the Royal Society of Victoria
PROGRESS IN OCEANOGRAPHY
PUBLIC MONEY & MANAGEMENT
QUATERNARY SCIENCE REVIEWS
REMOTE SENSING
REVIEWS IN AQUACULTURE
REVIEWS IN FISHERIES SCIENCE
SUSTAINABILITY SCIENCE
TOURISM MANAGEMENT
TRANSACTIONS OF THE ROYAL SOCIETY OF SOUTH AUSTRALIA
TRENDS IN ECOLOGY & EVOLUTION
WETLANDS ECOLOGY AND MANAGEMENT
WILDLIFE RESEARCH
WILEY INTERDISCIPLINARY REVIEWS-CLIMATE CHANGE
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Cumulative

http://dx.doi.org/10.1071/MF17330_AC

Fig. S2. Frequency histograms of the number of articles addressing the key marine climate-change questions (Questions 1.1–4.7 listed in Table S2) within the sectors of aquaculture, fisheries, conservation and tourism for each year from 2009 to 2015; National Climate Change Adaptation Research Plan for Marine Biodiversity and Resources (MNARP) and non-MNARP pooled. (See following page.)


2009
2010
2011
2012
2013
2014
2015
No. articles
0
10
20
30
40
50
60
1.1
1.2
1.3
1.4
1.5
1.6
2.1
2.2
2.3
2.4
2.5
2.6
2.7
3.1
3.2
3.3
3.4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
Aquaculture
Fisheries
Conservation
Tourism

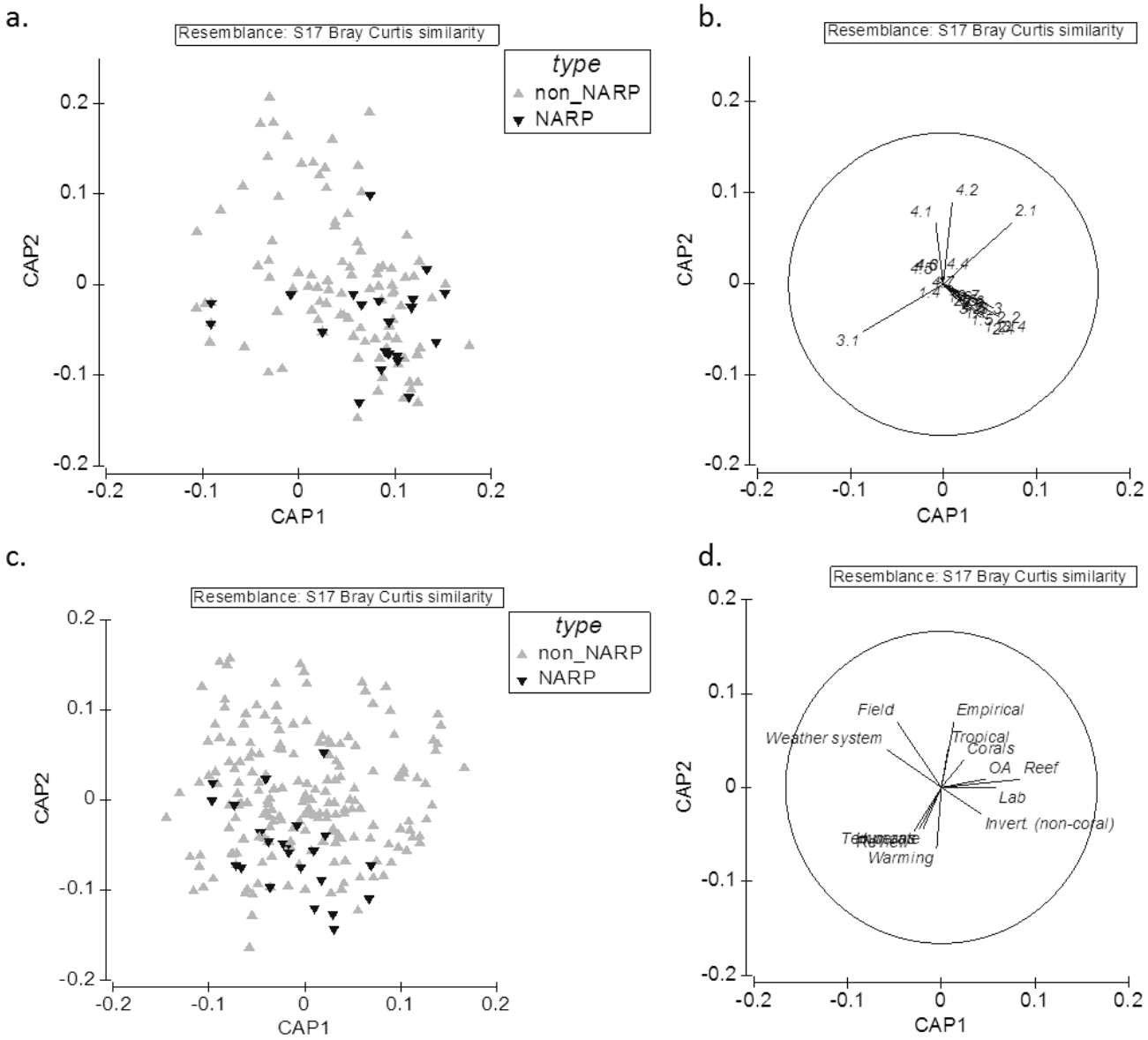


Fig. S3. (*a*) Canonical analysis of principal coordinates diagram showing spread of National Climate Change Adaptation Research Plan for Marine Biodiversity and Resources (MNARP) and non-MNARP articles, on the basis of focal score across priority climate-change questions (1-way PERMANOVA, $P < 0.0001$); (*b*) vector overlay showing direction and magnitude of separation of MNARP and non-MNARP literature, on the basis of each question; (*c*) CAP diagram showing spread of MNARP and non-MNARP articles, on the basis of study breath for (1-way PERMANOVA, $P < 0.0001$); (*d*) vector overlay showing direction and magnitude of separation of MNARP and non-MNARP literature, on the basis of the breadth categories with correlation of >0.2.

Reference

Holbrook, N. J., Creighton, C., Robertson, J., Vu, H., and McKellar, R. (2012). 'National Climate Change Adaptation Research Plan: Marine Biodiversity and Resources – Update 2012.' (National Climate Change Adaptation Research Facility: Gold Coast, Qld, Australia.)

Holbrook, N. J., and Johnson, J. E. (2014). Climate change impacts and adaptation of commercial marine fisheries in Australia: a review of the science. *Climatic Change* **124**, 703–715. doi:10.1007/s10584-014-1110-7