APN
ASIA-PACIFIC NETWORK FOR
GLOBAL CHANGE RESEARCH

FINAL REPORT

Understanding the interaction of ocean acidification and marine tourism for sustainable management of coral reefs

CRRP2019-05MY-Benkendorff

2023

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 Asia-Pacific Network for Global Change Research (APN)

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1. Summary

The combined effects of ocean acidification and marine tourism place intense pressure on sensitive coral reefs and threaten their ecological and economic sustainability. The combination of the world's highest coral cover and diversity, combined with the contribution of diving-related tourism to local economies, suggest these interactions may be disproportionately important for areas of South East Asia. Through this project, we surveyed coral reefs in four regions of South East Asia and developed a vulnerability index to establish the relative risks to breakage from scuba diving and climate-change-related events, including ocean acidification. We also surveyed the dive industry in each of these regions to assess their perceptions of the major risks to local coral reefs, their knowledge of ocean acidification, and the level of environmental stewardship in the industry. Dive stakeholders were also surveyed, using an online method, to provide insights into how and why they choose dive locations and their perceptions of the major threats, including ocean acidification. The project outcomes reveal that sites with relatively high vulnerability to ocean acidification and breakage occur in Tioman Island (Malaysia) and Maluku Province (Indonesia). Tioman Island and Hon Mun Island in Nha Trang (Vietnam) have the largest SCUBA dive tourism industries of the areas surveyed, with suggestions by most Dive Masters and Dive Company Managers that current activities exceed carrying capacity of the reefs in Nha Trang. Decline in the state of reefs was noted by all dive industry stakeholders across all regions. The main threats were identified as destructive fishing practices in all regions except Australia. Climate change was identified as a threat by some stakeholders in each region, but ocean acidification was rarely mentioned. SCUBA divers were generally less aware of ocean acidification than other threats to coral reefs. However, in all regions except Maluku, the SCUBA dive industry was aware of the concept of ocean acidification. Similarly, the majority of Dive Masters in Maluku Province were less aware of the impacts from diver-induced damage to coral. Most dive operators in all regions provide pre-dive training and briefings, although few are trained to intervene underwater when required to protect corals. Overall, most dive operators participate in environmental programs and SCUBA divers prefer providers with good environmental stewardship. These results highlight an opportunity to further engage Dive Masters in education on ocean acidification to empower them in non-regulatory controls for protecting coral during dive activities. We also recommend good governance of areas of high coral diversity, particularly those dominated by sensitive growth-forms. Such governance would provide opportunities to manage a range of threats, and should include appropriate regulation of the dive industry to ensure best practice, and nomination of a suitable carrying capacity to ensure long-term ecological and economic sustainability.

2. Objectives

1) Complete a meta-analysis on coral hardness, structure and the impacts of acidification.
2) Convene a transdisciplinary workshop to share knowledge on the implications of acidification for marine tourism.
3) Survey percent cover of coral life forms and damage to coral at 4 case study locations to assess the relative vulnerability of reefs.
4) Undertake stakeholder interviews with scuba dive tourism operators and surveys with divers and snorkelers to assess their knowledge and commitment to sustainability and environmental stewardship.

5) Undertake an environmental and economic risk assessment, combining data from the above objectives, to highlight the relative capacity and future sustainability of coral reef tourism in different regions.
6) Increase awareness of the potential fragility of hard corals under future acidification conditions to marine managers and scuba dive tourism operators, and provide educational tools for minimizing reef damage by divers.

7) Train research students within each of the four ASEAN countries to participate in the project.

3. Outputs, Outcomes and Impacts

Outputs	Outcomes	Impacts
Meta-analysis based on review of 362 peer-reviewed papers on coral density and porosity presented at the Project workshop. This synthesis was used to develop a standardised vulnerability rating for coral to ocean acidification. Plans for publications include a peer-reviewed paper (in preparation) on coral vulnerability at the different survey locations, and a literature review of coral vulnerability to ocean acidification.	Identifies lack of standardisation in methods to measure coral density. Identifies gaps in empirical data for many coral families. Very limited data currently exist on coral strength (breakage point) or likely effects of ocean acidification on coral density, porosity or strength. Based on our review, vulnerability to breakage is predicted as branching coral > plate/tabular > massive > submassive > foliaceous > solitary > encrusting.	Raises awareness on how variation in coral porosity and density influence vulnerability to ocean acidification and breakage. Provides incentive to fill gaps in the current knowledge of porosity and strength across different coral life-forms, families and under current versus future predicted conditions. Provides a considered coral vulnerability index for assessing risks to reefs based on coral life-forms.
Workshop held on “Understanding the interaction of ocean acidification and marine tourism for sustainable management of coral reefs” with an associated workshop report	Knowledge sharing across research team and with all stakeholders involved. Development of agreed methodology for surveying coral reefs across four regions.	Underpins rigorous data collection and enables comparison of standardised data for coral reef vulnerability across regions, both in this project and for future application in other regions.

	Agreement on survey questions for dive industry stakeholders. Development of quantitative method for summarising reef vulnerability (reef vulnerability index).	
Surveys of coral lifeform percent cover on 24 coral reefs across four countries completed and vulnerability indices calculated. Draft manuscript in progress for high impact journal	Standardised assessment of the relative vulnerability of coral across four regions. Identification of reefs at highest risk to damage from the combined effects of ocean acidification and tourism.	Increased awareness of risks to coral reefs according to the fragility of coral and pressure from dive tourism. Provides incentive for managers to preserve coral reefs at highest risk in diving hotspots.
Interviews completed with: 53 Dive Masters; 24 SCUBA dive company managers; and employees from two marine management agencies. Manuscript submitted to *APN Science Bulletin*.	Identification of regulatory and non-regulatory mechanisms for protecting coral reefs across four countries. Increased awareness of ocean acidification and relevance to diving impacts in the SCUBA dive industry. Multi-national knowledge sharing of concerns in the SCUBA dive industry to facilitate adaptive management in emerging diving hotspots.	Evidence to support international standards for managing the SCUBA dive industry in coral hotspots. Inclusion of education on ocean acidification and coral vulnerability to breakage in all pre-dive briefings. Empowerment of Dive Masters to intervene in poor dive practice. Empowerment of marine managers to work with and regulate the SCUBA dive industry to ensure sustainable growth.
Online survey of 75 SCUBA divers on threats to coral reefs and knowledge of ocean	Demonstrates a lack of knowledge, but high concern, about ocean acidification	Increased awareness of ocean acidification and the implications for coral

acidification. Manuscript submitted and under review for *Marine Policy*.	compared to other threats to coral reefs. Confirms SCUBA divers are willing to pay for well-managed coral reefs.	vulnerability to breakage in recreational SCUBA divers. Highlighted economic incentives for marine managers and SCUBA Dive providers to commit to good environmental stewardship.
Coral and Dive Stakeholder survey collated across four Asia Pacific Regions for an environmental and economic risk assessment. This has contributed to an APN perspectives article and will also contribute to a manuscript on coral reef vulnerability in preparation for a high impact journal.	Identifies environmental and economic challenges for the SCUBA dive industry in the Asia Pacific. Reveals gaps in knowledge on ocean acidification in different dive stakeholder groups. Indicates the majority of dive stakeholders across all regions believe coral reefs are currently in a state of decline. Highlights the impacts of COVID on the SCUBA dive industry.	Increased education on ocean acidification and risks associated with diver-induced damage on coral reefs. Recognition of the value of local knowledge on the threats and state of coral reefs held by the dive industry for future monitoring purposes. Increased understanding of multiple environmental, economic and social factors that threaten sustainable marine tourism in the Asia Pacific region.
Digital flyers with infographic and recommendations for marine managers and SCUBA divers to help reduce the impacts of ocean acidification.	Infographic shared on social media, the APN website and distributed to dive companies and other stakeholders.	Increased awareness of the potential effects of ocean acidification. Empowerment of SCUBA divers to take responsibility for their behaviour to reduce their impacts. Development of a tool to assist marine managers mitigate impacts of SCUBA diving with consideration of future ocean conditions.

Training of eight students and four ECRs in coral surveys and/or coral percent cover analysis. Training of three students and four ECRs in stakeholder surveys. Completion of three undergraduate student project reports and 2 Masters theses.	Increased expertise in coral reef assessment and stakeholder surveys in four Asia Pacific Regions. Publications submitted with three ECR co-authors (and additional ECRs involved in manuscripts in preparation)	Increased capability and more researchers undertaking rigorous data collection and high-impact, multidisciplinary research across four Asia Pacific regions.

4. Key facts/figures

- One multi-disciplinary workshop held with 18 participants from five countries.
- Data from 362 publications on coral density, porosity and strength used in a meta-analysis.
- Coral percent cover and relative vulnerability assessed on 24 coral reefs across four countries.
- Interviews conducted with 77 dive industry stakeholders.
- Online surveys completed by 75 SCUBA divers.
- Two manuscripts submitted to peer-reviewed journals and another two in preparation.
- One online APN perspective piece published and two information flyers produced for public outreach and management recommendations.
- Eleven ECRs trained in high quality multidisciplinary research and collaboration.

5. Publications

1. Benkendorff, K., Ab Lah, R., Ngoc, Q.T.K., Dimmock, K., Ode, I., Trinh, T.D. and Limmon, G. 2023. Ocean acidification and implications of the COVID-19 pandemic for the SCUBA diving industry in four regions in Asia-Pacific: Long-term and short-term challenges for the dive industry. APN Perspectives. https://www.apn-gcr.org/perspective/ocean-acidification-and-implications-of-the-covid-19-pandemic-for-the-scuba-diving-industry-in-four-regions-in-asia-pacific/
2. Apps, K., Heagney, E., Ngoc, Q. T. K., Dimmock, K., and Benkendorff, K. 2023. Scuba divers, corals reefs and knowledge of ocean acidification. Marine Policy, submitted Feb 2023.
3. Benkendorff,K., Ngoc, Q.T.K., Ab Lah, R., Ode, I., Dimmock, K., Trinh, D.T., Banda-Marquez, A., and Limmon, G. 2023. Comparison of dive industry perspectives on threats to coral reefs in four Asian pacific countries. APN Science Bulletin, submitted March 2032.

4. Benkendorff, K., White, Z., Imanjuntak, P., Ab Lah, R., Quang, T.M., Djakimann, C., Limmon, G., Binh, T.D., Zaccharia, R., Chelliah, A., Klaas, C., Harrison, P. Smith, S. 2023. Standardised assessment of coral reef vulnerability based on life-form, size class, percent cover and tourism pressure in four Asia Pacific Countries. Manuscript in preparation.
5. Benkendorff, K., Summer, K., Osbourne, C, Harrison, P. et al. Meta-analysis of coral denisty, porosity and strength. Manuscript in preparation.

6. Media reports, videos and other digital content

Southern Cross University circulated a media release on the workshop in 2019 and the story was run on NBN news Gold Coast and Channel 7 news Gold coast https://www.facebook.com/840702249361798/posts/2485737251524948/

Further media releases will be produced when manuscripts are accepted/published.

Two public flyers have been circulated on Facebook and are published on the APN Global Change Research Project site:
Public flyer for SCUBA divers:
https://www.apn-gcr.org/publication/protect-coral-reefs-under-climate-change-how-you-can-help/
Flyer for marine managers:
https://www.apn-gcr.org/publication/protect-coral-reefs-under-climate-change-recommendations-for-managers/
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7. Pull quotes

"Our research highlights the need for further, broadscale assessment of coral-reef vulnerability to climate-change throughout the Indo-Pacific region, and a pressing need to identify 'impact hotspots' to prioritise management initiatives." (Prof. Steve Smith, Southern Cross University, Australia).

"This study has played an important role, showing that the dive industry is concerned about the condition of coral reefs due to the impacts of climate change and that they are willing to accept regulations such as best practices standards and carrying capacity limits, if it would help protect coral reefs." (Alvin Chelliah, Senior Program Manager, Reef Check Malaysia).

"This is the first project conducted in Indonesia that provides data on the effect of ocean acidification and marine tourism that can be applied to science-based policy and management to ensure the sustainable utilization of coral reefs in Maluku." (Prof. Gino

Limmon, Centre for Collaborative Research on Aquatic Ecosystems in Eastern Indonesia)

8. Acknowledgments

We are grateful to Southern Cross University for Administering the multiparty project agreement. We thank all the project collaborators including Alvin Chelliah from Reef Watch Malaysia for assistance with the Tioman Island coral surveys, Thái Minh Quang from the Institute of Oceanography for assistance with Hon Mun Island surveys, Zoe White and Bob Edgar for assistance with Solitary Island surveys, Prandito Imanjuntak and Cilun Djakimann for assistance with Maluku coral surveys, as well as Huynh Trung Thao and Tran Nguyen To Uyen for stakeholder interviews in Nha Trang. Kirin Apps assisted with human ethics approval, design, implementation and analysis of the Diver Surveys. Chris Klaas tested the coral vulnerability index on a preliminary data set. Kerry Cameron, Anna Banda Marquez and Zoe White contributed to data analysis and synthesis. Kate Summer assisted with the workshop preparation and coral meta-analysis and Kathryn James provided the graphic art work for the flyers.

9. Appendices

1. Project Workshop Report

   Benkendorff, K. and Summer, K. 2019. Understanding the interaction of ocean acidification and marine tourism for sustainable management of coral reefs. Gold Coast, 2-9 Nov. 2019. Asia Pacific Network for Global Change Research Project Workshop CRRP 2019-05-MY Benkendorff

2. Meta-analysis presentation slides from the Project Workshop

   Benkendorff, K. 2019. Coral vulnerability to damage: Preliminary meta-analysis: Understanding the interaction of ocean acidification and marine tourism for sustainable management of coral reefs. Gold Coast, 2-9 Nov. 2019. Asia Pacific Network for Global Change Research Project Workshop CRRP 2019-05-MY Benkendorff

3. APN Perspective article

   Benkendorff, K., Ab Lah, R., Ngoc, Q.T.K., Dimmock, K., Ode, I., Trinh, T.D. and Limmon, G. 2023. Ocean acidification and implications of the COVID-19 pandemic for the SCUBA diving industry in four regions in Asia-Pacific: Long-term and short-term challenges for the dive industry. APN Perspectives.
   https://www.apn-gcr.org/perspective/ocean-acidification-and-implications-of-the-covid-19-pandemic-for-the-scuba-diving-industry-in-four-regions-in-asia-pacific/

4. Submitted manuscript (NOT FOR RELEASE PRIOR TO PUBLICATION)

   Apps, K., Heagney, E., Ngoc, Q. T. K., Dimmock, K., and Benkendorff, K. 2023. Scuba divers, corals reefs and knowledge of ocean acidification. Marine Policy, submitted Feb 2023.

5. Submitted manuscript (NOT FOR RESEASE PRIOR TO PUBLICATION)

   Benkendorff, K., Ngoc, Q.T.K., Ab Lah, R., Ode, I., Dimmock, K., Trinh, D.T., Banda-Marquez, A., and Limmon, G. 2023. Comparison of dive industry perspectives on threats to coral reefs in four Asian pacific countries. APN Science Bulletin, submitted March 2032.

6. Draft manuscript in preparation (NOT FOR RESEASE PRIOR TO PUBLICATION)

   Benkendorff, K., White, Z., Imanjuntak, P., Ab Lah, R., Quang, T.M., Djakimann, C., Limmon, G., Binh, T.D., Zaccharia, R., Chelliah, A., Klaas, C., Harrison, P., Smith, S. 2023. Standardised assessment of coral reef vulnerability based on life-form, size class, percent cover and tourism pressure in four Asia Pacific Countries. In preparation.

Southern Cross University

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ASIA-PACIFIC NETWORK FOR GLOBAL CHANGE RESEARCH

CRRP 2019-05-MY-Benkendorff
Project Workshop Report

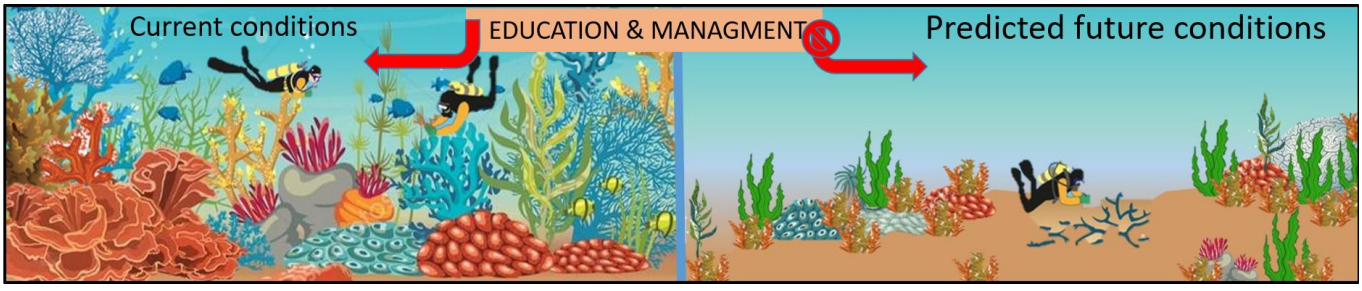
Understanding the interaction of ocean acidification and marine tourism for sustainable management of coral reefs

Kirsten Benkendorff[1,2] and Kate Summer[2]
[1]National Marine Science Centre, [2]Marine Ecology Research Centre,
School of Environment, Science and Engineering,
Southern Cross University

Workshop Location: Rm C6.17 Gold Coast Campus, Southern Cross University, NSW Australia

Dates: 2-6th November, 2019

Chair & Project coordinator: Prof. Kirsten Benkendorff
Email: kirsten.benkendorff@scu.edu.au



Project Principle investigators

Country	Name	Affiliation	Expertise	Dates attending	Hotel
Australia	Prof Kirsten Benkendorff	SCU MERC	Marine climate change	2-6th Nov	La Costa
	Dr Kay Dimmock	SCU MERC	Dive Tourism	2-4, 6th Nov	Bilinga Beach
	Prof. Peter Harrison	SCU MERC	Coral reef ecology	4th Nov	NA
	Prof. Stephen Smith	SCU MERC/NMSC	MPA management Marine biodiversity	3-6th Nov	La Costa
	Dr Elizabeth Heagney	OEH/ SCU MERC	Environmental Economics, Policy	4th Nov	NA
Vietnam	Dr Dang Thuy Binh	NTU IBE	Marine biodiversity & conservation	2-6th Nov	La Costa
	Dr Quach Thi Khanh Ngoc	NTU	Bioeconomic modelling, climate change policy	Not able to attend	NA
	Dr Si Vo Tuan	IO & Reef Check coordinator	Coral reef ecology MPA Management	2-4th Nov	Bilinga Beach
	Mr Van Hai Dam	Nha Trang Bay Management	MPA management Marine biodiversity	2-6th Nov	La Costa
Malaysia	Dr Roslizawati Ab Lah	UMT	Marine climate change	2-6th Nov	Bilinga Beach
	Dr Razak Zakariya	UMT	Marine habitat mapping, MPAs	2-6th Nov	Bilinga Beach
Indonesia	Dr Gino Limmon	Uni Pattimura	Marine biodiversity & conservation	3-6th Nov	La Costa
	Ms Inem Ode	DA U	Ecotourism, stakeholder surveys	Not able to attend	NA

Other workshop participants:

Country	Name	Affiliation	Expertise	Dates attending	Hotel
Australia	Mr Simon Hartley	SCU MERC	Coral surveys and diver impacts	3-6th Nov	La Costa
	Kate Bradshaw	SCU MERC	Project assistant	2-6th Nov	La Costa
	Jamie Kruusmaa	Reef Check Qld	Coral surveys	3-4th Nov	NA
Malaysia	Alvin Chelliah	Reef Check Malaysia		2-5th Nov	La Costa
Japan	Dr Rajendra Khanal	Tokyo Institute of Technology	APN project on risk and resilience in SE Asian coral reefs	2-5th Nov	Bilinga Beach

Program - Day 1 & 2

Date/ time	Activity	Presenter
Saturday 2nd November		
9:30- 10:30	Airport Pick up	
10:30 -12:00	Breakfast, shopping	
12:00pm	Hotel Checkin - rest/recover	
4pm	Hotel pickup - rm C6.17 SCU Gold Coast	Kirsten
	Welcome	
	Delegate introductions	All
	Project aims	Kirsten
6:00 - 8 pm	Dinner	
Sunday 3rd November - rm C6.17 SCU Gold Coast		
9:00 am	Hotel pick-up	
9:15	Introductory Presentations	
9:15	• Coral diversity and life forms	Peter Harrison (Zoom)
9:40	• Coral strength and acidification meta-analysis	Kirsten Benkendorff
10:00	Display of coral life forms	
10:15	Discussion of coral vulnerability	All
10:45	Morning tea	
11:00	MPA & Coral Monitoring Presentations	
	• Hon Mun Island MPA	Dang Thuy Binh, Van Dam
11:20	• Reef Life Coral Surveys - Vietnam	Vo Si Tuan
11:40	• Terengganu & Perhentian Island MPA	Roslizawati Ab Lab, Razak Zakariya
12:00	• Reef Check Coral Surveys - Malaysia	Alvin Chelliah
12:30 pm	Lunch	
1:30	MPA & Coral monitoring programs Presentations	
	• Solitary Islands & Cook Islands MPA	Steve Smith
1:50	• Ambon and Seraam Island coral reefs	Gino Limmon
2:10	Marine survey techniques and low impact diving Discussion	Simon Hartley
3:00	Afternoon tea	
3:15 - 5:00 pm	Discussion to confirm standardised survey methodology and data collection for coral surveys	All
6:00-8:00 pm	Dinner	

Program - Day 3

Date/ time	Activity	Presenter
Monday 4th November - rm C6.17 SCU Gold Coast		
8:45 am	Hotel Pick up	
9:00	Dive Tourism Presentations & Discussion	
9:30	• Dive tourism, Impacts & Stakeholder interviews	Kay Dimmock
9:45	• Preliminary interviews from Nha Trang	Kirsten Benkendorff
	• Discussion to refine questions for dive industry surveys	All
10:15	Morning tea	
10:30	• Reef Check Coral Surveys Australia	Jamie Kruusmaa
10:45	• Green Fins Program	Alvin Chelliah
11:00	• Online diver surveys	Kirsten/ Kay
11:15	• Discussion to refine questions and distribution network for diver surveys	All
12:15 pm	Lunch	
1:15	Coral Restoration and dive industry involvement	Peter Harrison
1:45	APN collaborative network on coral reefs	Rajendra Khanal
2:15	Discussion	All
	Stakeholder engagement & networking	
	• Mechanisms for engaging the dive industry	
	• Providing feedback from surveys	
	• Linking in to coral and diver networks	
3:15	Afternoon Tea	
3:30	Reef Vulnerability & Threats to the Dive Industry	
	• Assessing the Economic Implications	Elizabeth Heagney
	• Developing an Index for Vulnerability	Elizabeth Heagney
4:00 -5:00 pm	• Discussion	All
6:00-8:00 pm	Dinner	

Program - Day 4 & 5

Date/ time	Activity	Presenter
Tuesday 5th November - AM dive drip		
7:00am	Pick up from hotel	
7:30am	Diving Cook Islands (Gold Coast Dive Centre)	
1:30 - 2:30pm	Lunch	
Tuesday 5th November - PM rm C6.17 SCU Gold Coast		
2:30 - 3pm	Short break in hotel to change etc	
3pm - 5pm	Analysing coral survey data Coral point count/ Coral net	
6:00 - 8pm	Dinner	
Wednesday 6th November - rm C6.17 SCU Gold Coast		
8:45am	Pick up from hotel	
9:00am	Project discussions	All project CIs
9:30	• Roles and responsibilities • Mechanisms for sharing data • Publishing case studies • Integrating case studies for high impact publication	
10:15	Morning Tea	
10:30	• Public dissemination & education • Providing feedback to policy makers • Budget, distribution of funds for field work and scholarships	
11:30	Workshop wrap-up	
11:40	Lunch	
12:30 pm	Post-workshop tour to Currumbin Wildlife sanctuary	Optional ($50 for entry)

Day 1. Sat 2nd Nov.

This was an introductory session to enable participants to get to know each other and introduce the project aims and objectives. The roles and responsibilities of the participants in each country were discussed. A drop box was established for haring of files (later converted to a CloudStor account due to the large size of files preventing access by some with standard dropbox accounts). A group facebook account (APN coral: https://www.facebook.com/groups/695405440968131) was set up and all participants were invited to join.

There was some preliminary discussion on the availability of coral data, pH change and warming at each of the locations. Some historical data is available at the Solitary Islands Marine Park (NMSC) and in Nha Trang Bay (IO, Vietnam)

Day 2. Sun 3rd Nov.

An overview of coral diversity and life forms was presented by Prof Peter Harrison, followed by the meta-analysis undertaken by Prof Kirsten Benkendorff (summary slides attached) This was followed by a display of different coral life forms and photo session for local media (Figure 1).

Figure 1: Workshop participants with coral specimens (Image Kate Bradshaw).

An in depth discussion on coral vulnerability highlighted the following points.

- Acroporidae were identified as the most sensitive for human stressors and structurally susceptible to damage therefore could be a primary indicator for measuring coral reef health.
- Hard corals include a complex clade (porous, highly calcified, branching/other); and a robust clade (heavily calcified, robust skeleton, massive).
- Porosity and surface areas are likely to influence dissolution rates in an acidifying ocean
- Colony size, shape, branch thickness and skeletal density will determine fragility and susceptibility to diver induced breakage (e.g. Figure 2).
- At the reef scale, the coral composition, as well as the structure and complexity of the reef influences reef health and susceptibility to damage (e.g. Figure 3)
- A likelihood matrix/risk matrix could be applied (e.g. Table 1).

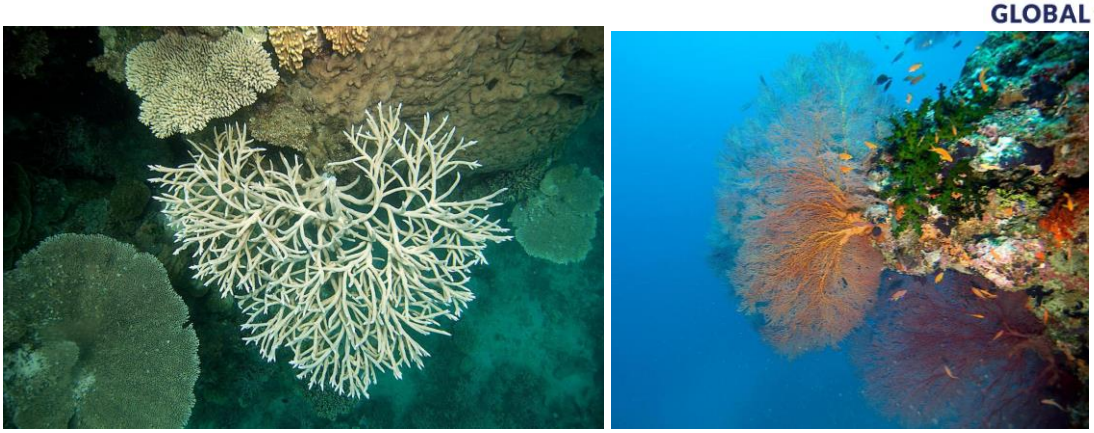


Figure 2: Examples of fragile coral (images Simon Hartley)

Figure 3: Example of complex reef in good condition (left) and low diversity reef in poorer condition (right) (images Simon Hartley).

Table 1: Example of a risk matrix to assess the vulnerability of coral reefs to ocean acidification and SCUBA dive damage.

			Likelihood/probability					
			High		Medium		Low	
			6	5	4	3	2	1
Risk/Severity	High	6						
		5	e.g. ↑ Increasing branching/plate corals ↑ Decreasing skeletal density ↑ Decreasing branch thickness ↑ Decreasing colony size		e.g. ← increasing coral percent cover ← increasing habitat/reef complexity ← increasing number of gorgonians ← increased distance from moorings ← increasing number of dive boats			
	Medium	4						
		3						
	Low	2						
		1						

In the middle of the day we heard presentations from a range of speakers (Figure 4) including Dr Binh Dang and Dr Vo Si Tuan on the Hon Mun Island Marine Protected Area and coral reef monitoring in Nha Trang Bay, followed by Dr Roslizawati Ab Lah on Perhentian Island marine protected area. Dr Razak Zakariya introduced us to seafloor bathymetry mapping techniques to detect coral reef complexity. Mr Alvin Chelliah introduced the Reek Check Malaysia monitoring program, highlighting the ecodiver certification and annual survey report. Prof Steve Smith presented an overview of the Solitary Marine Islands Marine Park biodiversity and monitoring and Dr Gino Limmon provided an insight into the coral diversity in Ambon, his current coral restoration programs and emphasized the importance of local knowledge. Some important points form the discussion included:

- Threats are different in different regions and need to be ranked.
- We need to think about how divers can feel that they are part of the solution and convey this.
- Need to communicate to tourism providers on the threats and opportunities to become involved in environmental stewardship and restoration programs.
- Reef Check surveys only collect on broad life forms, but there may be capacity to additional data.

Figure 4: Images of some of the presenters and presentations during the conference: top left Dr Binh Dang; Top right Dr Vo Si Tuan; Middle left Dr Roslizawati Ab Lah, Dr Razak Zakariya and Dr Vo Si Tuan; Middle left Mr Alvin Chelliah; Bottom left Dr Gino Limmon; and bottom right Prof Steve Smith.

Towards the end of the day Simon Hartley gave a presentation on low impact diving techniques (Figure 5), emphasising it was essential that researchers collecting data on coral reefs don't cause any damage. Simon also provided suggestions for monitoring community structure and the incidence of damage using control sites (ie. non/less dived sites) for comparison with more heavily dived sites and the need to consider other factors in analysis e.g. depth. Simon also shared a number of resources including a poster (Figure 5) and videos on low impact diving.

Figure 5. Simon Hartley's presentation and on poster on low impact diving techniques.

This was followed by an in depth discussion on the coral survey methodology, with important points including:-

- The trade-offs in image quality and practicality for systematic photographs vs. video transects
- How do we know if coral breakage is from divers or otherwise? Assumed or "other" as per reef check.
- Consider habitat type; algal dominated areas harder to see damage
- Consider condition/index thresholds where management has to intervene
- Can we draw on data that we already have? existing video transect data for Solitary islands; Ambon (?), Hon Mun long term data available for 2 sites, 1 with low diving, 1 with high, impact already from typhoon (how do we distinguish?)
- We want to detect differences in vulnerability between locations and between sites within locations
- We need to relate back to the future vulnerability of the dive industry. How important is the dive industry to the local economy, how good are the practices, and how fragile is the reef – combine into index.
- We need to demonstrate application of the index using the case studies; method needs to enable application to other sites.
- How can local managers use data from the project? It would be useful to show current level of damage as this is also important feedback for the dive industry.
- However, damage is difficult to assess; How can we demonstrate if there is significant damage and how can we relate this carrying capacity? Which areas have more breakage?
- Reef check data o damage only identified boat groundings and anchor damage, "other" for smaller breakage including diver damage and destructive fishing, broken rubble.
- Best approach is to include undived and heavily dived sites.
    - 1st component: % hard coral cover, life form/dominants;
    - 2nd component: damage (big- boat/anchor; small-diver/other)
    - 3rd component: additional data (trash?)
- Need a minimum of 3 transects at dived and undived sites at each location for statistical power

- Another possible option is to rate the degree of use. scale 0-6 diving intensity; 2 sites, 4 transects within each
- Design could be challenging in Ambon, not many heavily dived sites; Banda?
- Could look at as many sites as we want to for relative vulnerability based on % cover of vulnerable species and existing/likely impact from diving; don't have to have the same design everywhere?
- Snorkelling damage shallower water; need to be parallel to coastline so as to keep same depth. Positioning of transects will be site specific and should account for depth
- Consider 2 people doing transects: 1 person to assess damage, the other to assess cover (GoPro); some existing data for Ambon, Malaysia and Solitary Is.- ideal scenario is to collect new video data, budget considerations
- Could we fund masters/IP students to participate in data
- Is repeated sampling required for the surveys or just one representative set of surveys. All agree once only but seasonal influences may need to be considered.
- A standardised coral survey protocol has been developed and attached separately.

Day 3. Mon 4th Nov.

Day 3 commenced with a presentation by Dr Kay Dimmock (Figure 6) on the diver tourism industry and a summary of the literature on diver impacts on coral reefs. This was followed by a presentation by Prof. Kirsten Benkendorff which provided insights into preliminary surveys of dive shop managers and dive masters in NhaTrang Vietnam (Figure 6).

Figure 6: Presentations on the dive tourism industry and stakeholder interviews by Dr Kay Dimmock (left) and Prof. Kirsten Benkendorff (right).

The group then participated in active discussion about the dive industry surveys with the following points raised:

- We need to engage dive "guides" not only dive "masters"
- There are components to consider: inherent ecosystem features dependent on vulnerability, and vulnerability related to usage; do we need to determine ecosystem vulnerability before we can refine survey questions?
- We need focus on what we to capture in the vulnerability index; the surveys need to be structured to capture rigorous information to feed into publications and to authorities
- The industry surveys should focus on case study locations; we can do internet searches for dive companies
- We may get different responses based on how old the dive company is/how long they have been involved in the industry
- How do we eliminate bias?; generally, those that participate agree with the objective of the study

- We could do two-tiered survey/sub-surveys, e.g. employment and economic surveys that are less threatening, then select which companies to follow up with. However, this would need to be standardized across locations and in Ambon and Solitary Islands, there are not many dive operations so it should be possible to capture all.
- The surveys could be pitched around idea of how the dive industry contributes to the local community; framing for local relevance rather than environment.
- Lack of knowledge about acidification and diver impacts is a risk itself, need to capture this.
- Competition among local dive shops may influence answers; may feel pressure to give right answer and may overestimate ecological knowledge/practices.
    - In Nha Trang there was a tendency to criticise to trash other dive shops; need to clearly communicate that the surveys are de-identified
    - Criticism of other dive operators is also a way to understand what is going on, it can provide insights into illegal activities.
    - Old school vs new school businesses, new bring in big crowds and have less understanding, old don't necessarily want to be told what to do but can have better practices.
- There is an incentive for dive operators to say there is no carrying capacity (for business growth), someone who says there is a carrying capacity may provide a more reliable result
- The answers also dependent on who is conducting the interviews- local vs. western interviewer; need to ensure local interviewers at all locations.
- We also need to consider where the divers are coming from e.g. local or big groups (Chinese and Russian). Add questions to assess the perceived market like:
    - Where are divers coming from?
    - How well is the information provided by operators received by the tourists?
    - What are activity levels /patterns across the year? (per day/per year)
    - What is the average/maximum size of groups that go out
    - Ratio of divers to dive guides (there is a limit to numbers for effective supervision …find out what these are)
- Also need to establish their contribution to the local community, environmental knowledge, dive briefings and economics; two-tiered interview process good idea.
- A lot of big groups bring their own dive masters, whether they have the same ethic as locals is debatable; need separate interviews for big/small groups?
- High turnover of dive industry staff – should we include frequency of dive master turnover in survey?
- Examples of interview questions have been attached separately and uploaded into Cloudstor.

After morning tea we had invited presentations from Jamie Kruusmaa on the Reef Check Australia program (Figure 7). This outlined their stringent training volunteers for classifying organisms. This led to further useful discussion coral life forms, assessing damage and vulnerability.

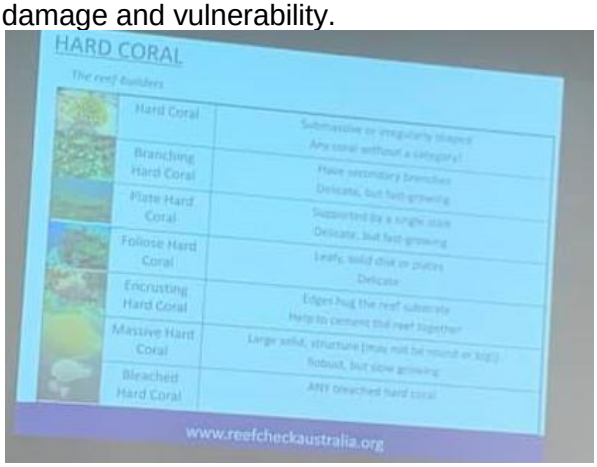


Figure 7. Invited presentation by Jamie Kruusemaa on the Reef Check Qld program and life form categories for hard coral.

Alvin Chelliah then presented information on the Green Fin program (greenfins.net, all resources are freely available). Alvin explained the program which provides training and environmental accreditation for the dive industry in Malaysia. Green Fin members must follow a code of conduct. Alvin outlined the benefits and challenges, emphasizing that these projects only work if the dive industry wants to participate. Once operators start making money they often stop caring about the environment. We need to make them care and understand the vulnerability of the reef and consequently the industry. Asking questions can help identify problems that need to be solved e.g. more mooring buoys to stop anchor drag. Alvin also noted that many European tourists are looking for holiday experiences that don't impact the environment. Consequently, there are marketing benefits to Green Fin accreditation - companies can differentiate by being green. Some environmental practices can also save costs e.g. water dispenser, oil disposal. Additional points of discussion led to further considerations for the dive industry surveys

- We could ask would you consider implementing this practice if it saved you money?
- Greenfins certification points are all principles of good business practice. We could ask if they know of/are involved with green fins
- Some will think they are doing the right thing and don't need accrediation
- The dive industry in Australia is more regulated; professional industry awards are relevant there.
- Possibility for leveraging funds from dive organisations/marine parks/industry? How much does a dive cost in each country and where does the money go?
    - Australia- $100-200/dive,
    - Ambon/Bali- AU$35/dive,
    - Vietnam US$30/dive,
    - Malaysia- AU$30.

- Greenfins criteria could be used for monitoring project outcomes? Integrate into survey/feedback

Professor Kirsten Benkendorff then opened the discussion on surveying divers, snorkelers about their experience and expectations of diving in each of the locations. An online survey was proposed using SurveyMonkey or Qualtrics that could be disseminate via dive forums. It was suggested to include questions that provided choice of yes/no, Likert scales and using images that respondents could select from as examples (e.g. reefs in good and poor condition). The survey should cover diver experience and expectations, size of dive group and number of other groups at the same location, willingness to pay more for sites with fewer tourists and/or better condition, perception of the condition of the reef and whether they would return based on their experience and in future if ocean acidification degraded the reefs. The following discussion included:-

- How do we capture an unbiased data-set?
- Do we ask them to identify the dive shop specifically or just location?
- Dive experience might be different depending on what they have seen in the past; consider open-ended question for experience at the site
    - to understand experience we also need to understand type of dive site e.g. question re. was the site coral dominated, wall diving, muck dive, wreck dive
    - need to flesh out previous experience of respondents (no. of dives, no. of regions previously dived)
    - categorize frequency of diving e.g. have dived 0-20, 20-50 times, or x times per year? where else have you dived- open ended or categorical (define regions/countries)
    - could list name and number of dives
    - list three favourite dives?
- Survey should include pictures to which one matches their experience (less subjective)
    - should also include a question about what they expected to see?

  - need help selecting photos appropriate for each site; may need to sign in from different locations
- Questions about the cost of the trip could include:
  - how much did you pay,
  - how much would you be willing to pay after your experience?
  - would you be willing to pay an additional levy to maintain current condition or improve site
  - would you pay more for operators with environmental accreditation?
- Question about damage need to be specific
  - did you see evidence of damage from tourism too general - how do they define damage or know if it's from tourism?
  - could ask specifically, did you see people standing on the reef or breaking coral; did you see any anchor damage?
- Opportunity to understand visitors view of carrying capacity, how big was the group, was there too many divers in the water
  - how many divers were there at the same site? make classes bigger e.g. 1-10 (standard boat), 11-30, 31-50, >50
  - how many dive groups? and how many other divers were in your group? add snorkellers too.
  - same with dive boats question? Change to dive boat/ tourist boats. Categories 0-3, 4-10, 11-30
  - were there too many divers/boats?
- Provide a proper experimental framework, break down what people are willing to pay for different scenarios e.g. number of other groups, people in the water, with reef of given condition will reveal a number of different preferences (discussed later in Liz Heagney's presentation)
- How bad will people let it get? this type of info is important to define how people make decisions series of photos showing progressively degraded condition
- would you return to the site? if not, why not? this is important because people might not come back for other reasons (e.g. they got robbed, or stung by something)
  - series of photos progressively more degraded, would you return if it looked like this..? make it clear that returning to the site is a question of condition
  - might not be interested in coral, maybe other organisms (fish or turtles); make clear that we are talking about the reef, not just corals; we need to say what is attracted by the coral reef ecosystem. Include a question re. what did you come here to see?
  - use series of photos used previously, I would not dive here if the reef looked like this, see if responses are the same.. multiple questions to triangulate
  - include a question re. how do you select sites you want to dive? Is it economic or based on what they want to see, or just a matter of convenience;
  - could rank motivations to dive the site e.g. specific feature, cost, I was here anyway, look for sites with best reef, proximity to other tourist destinations, friend suggested
  - pre-diving: why did you choose the site, and post-diving: what was the best thing about the dive. Specify information on reef condition, not just on coral condition.
- The order of questions needs to be grouped rather than randomised
- Social media/websites question, wording needs to change
  - I get my information from friends, websites, social media etc. tick/rank
- Ask if there is a reason why they chose the dive shop e.g. eco certification, lonely planet
- Good to say that we are valuing greenfins/the environment in general as an argument for government funding

After lunch Dr Rajendra Khanal (Figure 8) provided an overview of his APN funded collaborative project on corals reefs and the range of impacts they will be looking at. He outlined their network and propose locations. As feedback it was pointed out that there are no coral reefs near Hanoi or in Ha Long Bay.

Rajendra also outlined some ecotoxicology studies and the group provided feedback that crustacean bioindicators like Daphina are not suitable indicators for impacts on coral due to different life history and structure. Rajendra's presentation did highlight the potential need for a survey question to dive operators and divers on the awareness of the impacts of certain ingredients in sunscreens on corals.

Professor Peter Harrison (Figure 8) then gave a presentation on his coral reef restoration program, including success in the Philippines and current work in the Great Barrier Marine Park, highlighting some positive engagement with the dive industry. The costs of restoration (and the value of intact reef), needs to be clearly communicated to government to highlight why they should be protecting reefs. The messaging around restoration needs to be clear, we can't replace reefs easily and cheaply.

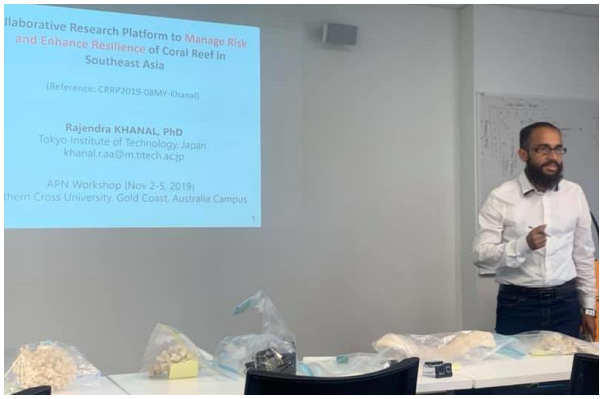


Figure 8: Invited presenter Dr Rajendra Khanal (left) and project investigator Professor Peter Harrison provide summaries of other related collaborative projects on coral reef sustainability.

The group then had an extended general discussion on standardizing and implementing the coral surveys and assessing vulnerability. The following points were raised:-

- Use of the CoralNet database – this enables us to contribute data to global network, standardised, data from other groups could feed back into this project.
- Some contributors might need more support than others
- Ecosystem service valuation is harder to sell, longer term; regional economic impact assessments have a lot of traction, but different/changing arguments for different priorities
- Points for standardizing the survey data
    - mostly interested in depth 8-12 m,
    - If at constant swimming height can assume size of coral e.g. > frame width, between x-x% of frame
    - miss a lot if close, swim 1m above transect and close, or go with frame occupation if close; 30 cm height, wide angle setting would capture coral ~1m wide
    - Include scale in photos?; some people use posts - good for still shots but not so useful with video
    - include measuring tape in videos? Width of measuring tape is useful, even if we can't see the numbers;
    - preference for stills vs. time lapse vs. video? stills good, if site impacted by surges (can stabilise and focus) but lose context of what's in between. Conceptually simpler using video, perfectly usable frame grabs if swimming slowly enough but potential loss of resolution
    - Possibility for using two cameras at once, video for frame grabs of videos and time lapse
- Points for coral classification for vulnerability (see summary Table 2)
    - hope to ID genus if possible, at least life forms (e.g. Acropora branching, foliose etc).
    - Acropora has many life forms- genus doesn't necessarily give life form
    - There are many more important life forms than those we are looking at, although some aren't used very consistently; could collect all and then collapse if needed?

  - life forms also vary within species with depth, sediment etc. so chosen categories should be sufficient
  - Unclear if we can add additional comments/subcategories in CoralNet *
  - classes for size: 1. <20 cm, 2. 20-50 cm, 3. >50cm (greater than frame width)
  - size and height matter re. breakage: coral colony size and shape; branch thickness and length; classes for branch length: 1 (<30cm), 2 (30-50cm), 3 (>50cm)
  - higher = wider for branching corals, assume proportional to height
  - Also is it of a reproductive size or not? This will vary between species, could be too difficult to assess.
  - need to keep this simple because others need to potentially apply. Measure size of vulnerable corals only?
- Points for vulnerability assessment
  - ocean acidification and porosity; the corals that are currently susceptible are going to keep being susceptible
  - the way the whole reef is structured can have an influence on overall vulnerability; how do we capture reef morphology?
  - can do from video, but better to take a wide angle photo of the site; take contextual images of the whole reef; important to have reminders of whole reef change over time
  - how do we rank vulnerability of different reef features? might be part of site description but probably can't go into index
  - divers might be more likely to land on flat reefs; is current worth considering? re. divers holding on to reef
  - combined impacts of tourism, including coastal development and sedimentation; large plate structures can capture more sediment, so even more vulnerable;
  - if it is a pristine site, what other impacts/infrastructure are likely e.g. hotels, dredging, clearing
  - habitat features e.g. inherent features of the reef are additional factors- could have a secondary risk framework for secondary factors
  - this is where dive industry surveys feed in, bring in other factors e.g sunscreens, sedimentation, hotels..
- Categories for classification of percent cover;
  - project is about coral reefs, not just scleractinian corals, so what are the important species/indicators?
  - need to include gorgonians as people like to see these
  - also Millepora; not all Acropora are as sensitive as one another, do we want to determine least-most sensitive genus?
  - need to look at all life forms (not just sensitive ones) and then determine relative proportions
- Will write up standard method for survey and GoPro (Attached separately and uploaded into CloudStor)

Table 2: Suggested categories for coral life forms

Life form	Genus	Colony size (cm)	Branch thickness (cm or class)
Branching	Acropora	<20, 20-50, >50	<1, 1-3, >3
	Other (non-Acropora)	<20, 20-50, >50	
Foliose	All	<20, 20-50, >50	
Encrusting	All		
Massive	All	<20, 20-50, >50	
Plate	All	<20, 20-50, >50	
Soft	All	<20, 20-50, >50	

In the last session on Day 3, Dr Elizabeth Heagney presented on environmental economics and how to construct willingness to pay surveys (Figure 9). She explained how economic value accrues to visitor/tourist, whereas economic impact accrues to community; both are relevant to this project. She provided examples of survey diver questions that provide options between two scenarios e.g. How much would you be willing to pay to maintain/visit in x condition, with additional variables (crowding, damage levels, diversity, number of sites, environmental accreditation). It is also possible to include future scenarios; convey monetary, social and environmental values in one question. She explained that dit is not necessary to survey a large number of participants to get results; ~100 will be sufficient to get an idea of where the maximum values lie and enable management to prioritise.

Figure 9: Dr Elizabeth Heagney (Left) providing valuable information on environmental economics to APN workshop participants.

Further points discussed regarding the stakeholder interviews and economic vulnerability assessment

- Outcomes should be communicated back to dive operators
- Two economic indicators for the importance of coral condition: 1. would you go there, 2. when you are there how much do you spend
- Consider demographics - different countries of origin have different spending patterns
- Market changes – bulk tourist groups spend most money before they arrive
- Relative sensitivity – how big is the tourism dollar relative to other resources? Is this important to build into surveys?
- Tourism is not one sector – accom, food, souvenirs
- Business survey – recommended to get info from operators; use simple % system instead of dollar value to determine relative spending/income, short; easier and less threatening esp. for small/unregulated business, determine local and imported capital and where benefits accrue; island communities often <20% retained benefit
- Length of survey
    - longer is better for assessment but impractical, but need to decide which information is most important to meet project objectives
    - important to determine what we can get from existing information and what we need from primary and secondary surveys so we don't make them too long
- Can reveal the value of improving condition
- beyond the current project, this sort of modelling could be really powerful for gaining funding; we should specify plans to value add in the future in the project report
- If we built in depreciation of the environment into the business survey, could it return a net negative financial value for the region, re areas where the amount retained is low anyway? Need to compare net retained with depreciation of natural capital value

- the way you frame questions is important; would you pay money to maintain *x*km^2 in *x* condition gives value per unit area of condition; there is a scaling effect according to how much someone has e.g. how much would you pay to protect 1 species could be the same as willingness to pay to protect 100 species
- we often know values but important to link to condition; decline is incremental; it is possible to determine thresholds

Day 4. Tues 5th Nov.

Most of the workshop participants joined a field trip to Cook Islands (Figure 10). Divers undertook video transects trialling different GoPro camera settings at two sites. Project coordinator Professor Benkendorff was interviewed by two local news networks, featuring footage from the field trip (e.g. Figure 11).

Figure 10: Images from the workshop field trip to Cook Island, Gold Coast, Qld, Australia.

Figure 11: 7 News media coverage for the APN collaborative project including footage from the workshop video transect coral surveys.

After the field trip Go Pro cameras were handed out to each of the location teams with some basic instructions. Further discussion points on field surveys and GoPro settings include:

- Need to charge/check/test Go Pros before you go out!!
- All use GoPros rather than compact camera for standardisation
- Recommended setting
    - Wide angle,
    - 4K resolution,
    - 30 sec frame rate (under video setting);
    - set video screen to continuous view so screen doesn't black out to save battery;
    - red filter (colour assists with ID)
- Survey Transect standardised to facilitate comparison of % cover and species richness
    - 25 m long transect,
    - 50 cm from substrate (calibrate with ruler),
    - 3 min (constant swim speed)
    - Measuring tape in video for scale, can use finger
- Follow profile but don't change the camera angle
- Data analysis
    - Extract 20 images,
    - 10 points within each = 200 points
    - Select images randomly (rather than systematically at set time/distance intervals)
- Possibility for using two GoPro's simultaneously - one recording video and other taking stills; compare resolutions.
- Time lapse – take more than we need (36), randomly select 20, move to next selection if blurry; ensure swimming speed constant to avoid overlap
- Rugosity measurement – index of complexity, discussion of techniques (pole/probe); develop complexity index 1-5 depending on complexity
- Processing data in CoralNet:
    - select labels,
    - export as .csv file, so everyone can import and use the same;
    - start with ReefCheck Qld list; Steve to draft; ensure "verified"
    - Classify everything we are looking for, everything else as "other"
    - red algae and green algae (or just algae)
    - Find out whether we can collapse higher classifications e.g. species into life form (not in CoralNET but can do in excel if entered at highest resolution)
- Possible to do larger multivariate analysis across regions, independent of vulnerability

Day 5. Wed 6th Nov.

A final discussion session was held involving project chief investigators only.

- The roles and responsibilities of investigators within each location team and across the entire project were confirmed.
- The dropbox folders were shared but subsequently changed to a CLoudStor folder on AARNET (https://cloudstor.aarnet.edu.au/plus/apps/files/?dir=/Shared/APN%20coral%20reef%20project&fileid=3987470201)
- The project agreement and intellectual property clauses were discussed. The team agreed to equal and joint ownership of IP
- All parties must have sufficient insurance coverage, or self-insurance, to cover the collaborator's role on the project
- All publications must comply with the requirements of the APN Publications Guide
- SCU to set up multi-party agreement. This is a legal document (now signed by all parties)
- A publication strategy was discussed whereby CIs could lead publications based on data within individual countries and the project lead investigator would lead the integration of case studies for high impact publication
- Stakeholder engagement and dissemination would include
    - Resources to improve dive industry awareness
    - Use of social media for public outreach
    - Policy recommendations - targeted for specific case study locations and integrated for Global networks
    - Within country media releases, collect footage for podcasts etc
- Budget distribution was agreed on for in country field surveys, interviews and student recruitment
- The possibility of leveraging additional funding was discussed.
- CoralNet – all sources created for APN project and all project participants present have been registered
    - Video tutorials: https://vimeo.com/channels/coralnet

Before closing, Southern Cross University Vice Chancellor Professor Adam Shoemaker gave a vote of thanks to the international collaborative team of investigators. A final group photoshoot was held (Figure 12) before departing and a few participants joined an additional field trip to the Currumbin Wildlife Sanctuary.

Figure 12: Closing of the APN workshop on the Impacts of Ocean Acidification and Diver Tourism on Coral Reefs.

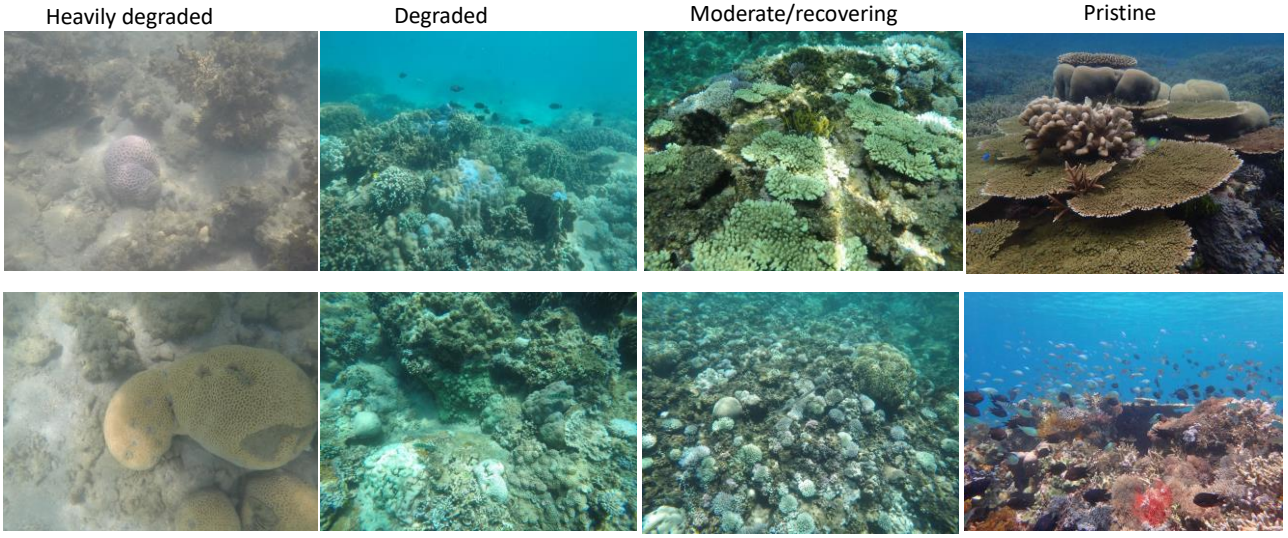
PRELIMINARY RESULTS

Coral Vulnerability to Damage
Preliminary Meta-analysis

Kirsten Benkendorff

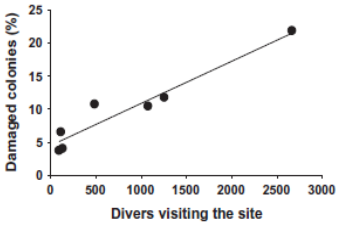


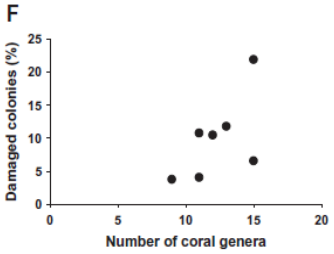
Reef states

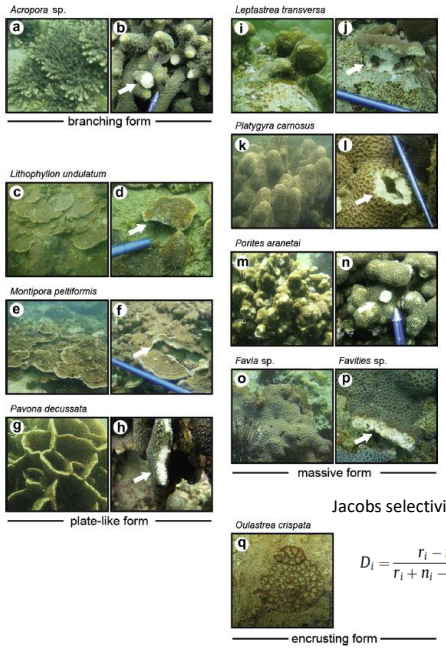


Susceptibility to breakage

Au, A C-S, Zhang, L., Chung, S-S, Qui, J-W. 2014, Diver associated coral breakage in Hong Kong: Differential susceptibility to damage. Marine Pollution Bulletin 85: 798-796

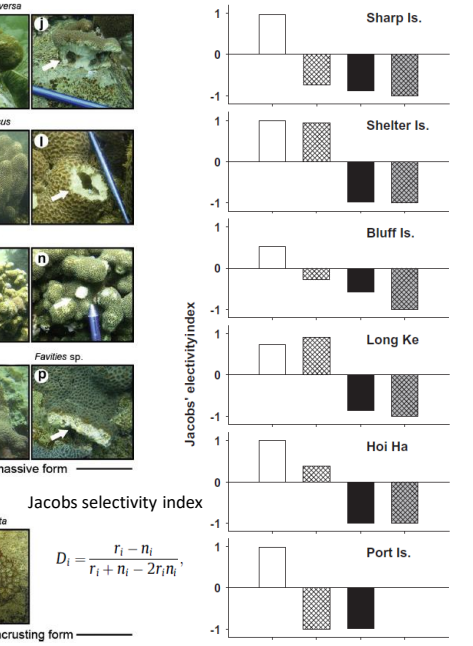






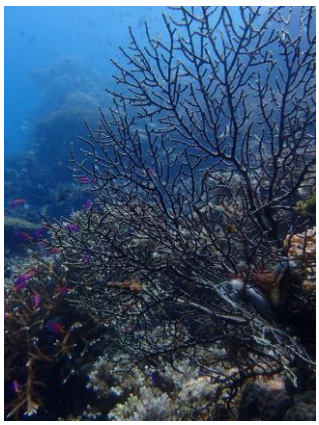
Jacobs selectivity index

$$D_i = \frac{r_i - n_i}{r_i + n_i - 2r_i n_i},$$



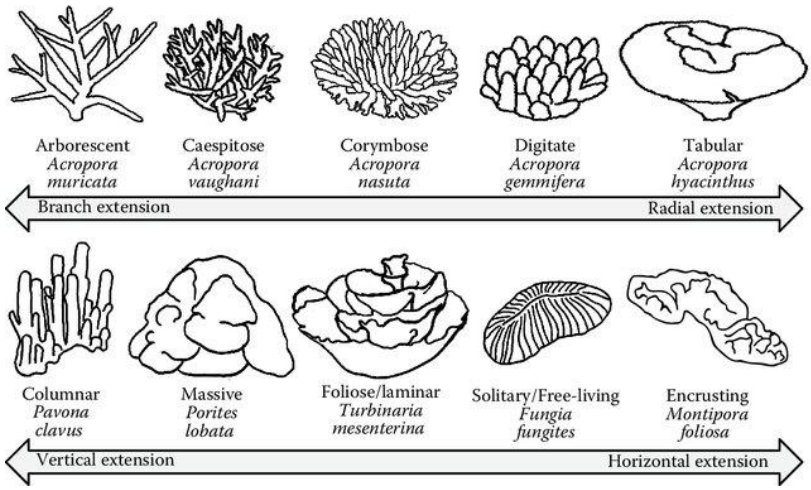
Factors influencing coral vulnerability to damage

- Colony structure
  - Life/growth form
  - Colony shape factor
- Growth rates
  - Linear extension rate
  - Calcification rate
- Skeletal strength
  - Density
  - Porosity
  - Mechanical strength



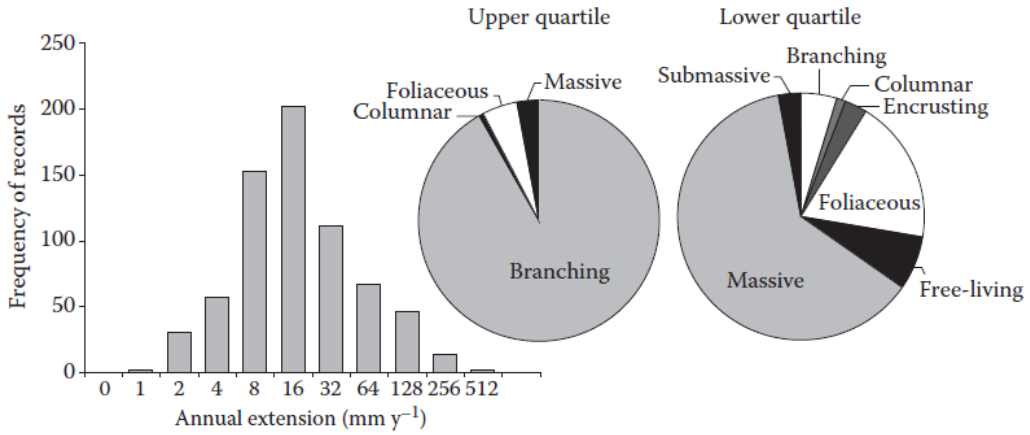
Major growth forms of coral arranged according to major growth axis

Prachett *et al*., 2015 Spatial, temporal and taxonomic variation in coral growth – implications for the structure and function of coral reef ecosystems. *Oceanography and Marine Biology: An Annual Review.* 53, 215-295



Variation in annual extension rates

Prachett *et al*., 2015 Spatial, temporal and taxonomic variation in coral growth – implications for the structure and function of coral reef ecosystems. *Oceanography and Marine Biology: An Annual Review.* 53, 215-295



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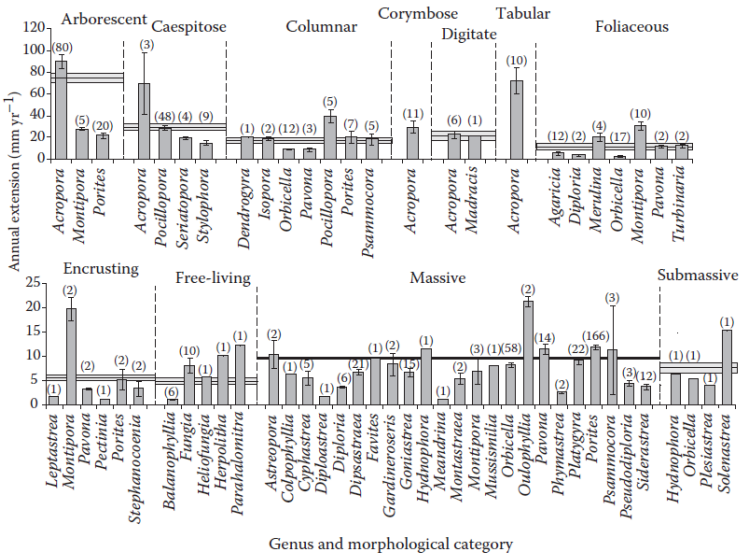
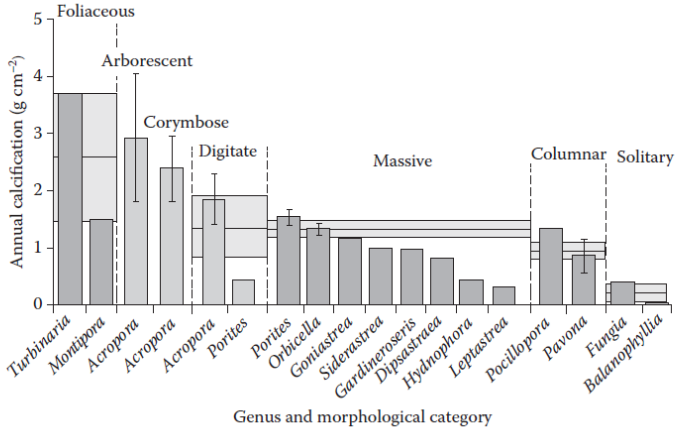


Annual calcification rates

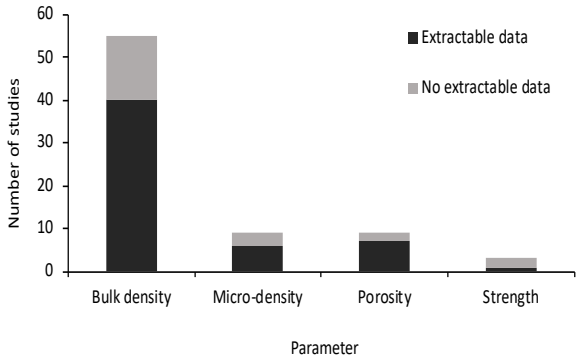


PRELIMINARY RESULTS

Meta-analysis

SCU Undergrad project student Caroline Osborne

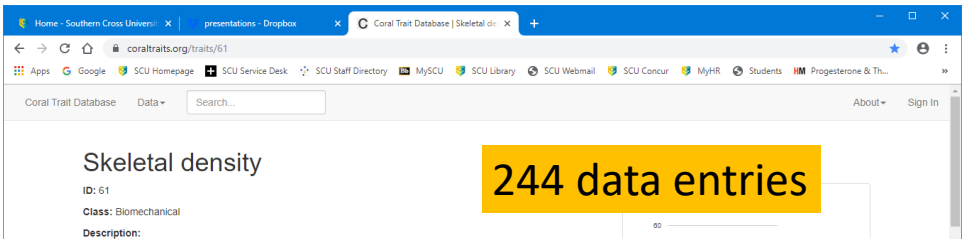
Search terms	Hits: Web of Science	Hits: Scopus
Scleractinia*	5512	4313
Coral AND (porosity OR density OR hardness OR strength)	5096	5032
Coral AND (acidification OR (elevated OR increased AND CO_2))	3416	1273
((Coral AND (porosity OR density OR hardness OR strength)) AND ((acidification) OR (elevated OR increased AND CO_2)))	432	117
Relevant papers*	61	



Only **5** examine the effects of ocean acidification effects on coral skeletal density or porosity

Coral traits database

https://coraltraits.org/traits/61



Acropora aspera

101838	Skeletal density	0.92 (g cm-3)	Show

Acropora austera

159744	Skeletal density	1.44 (g cm-3)	Show

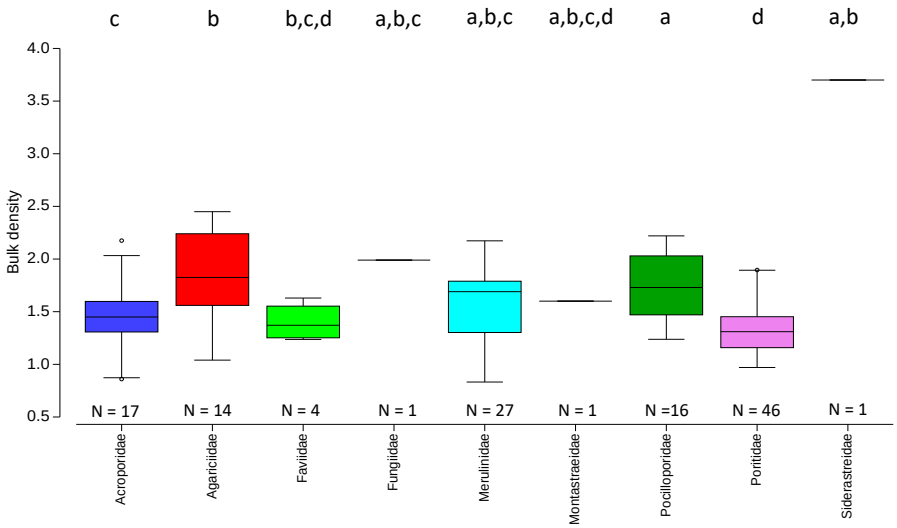
Acropora cervicornis

99196	Skeletal density	0.304 (g cm-3)	Show
99201	Skeletal density	1.693 (g cm-3)	Show

PRELIMINARY RESULTS

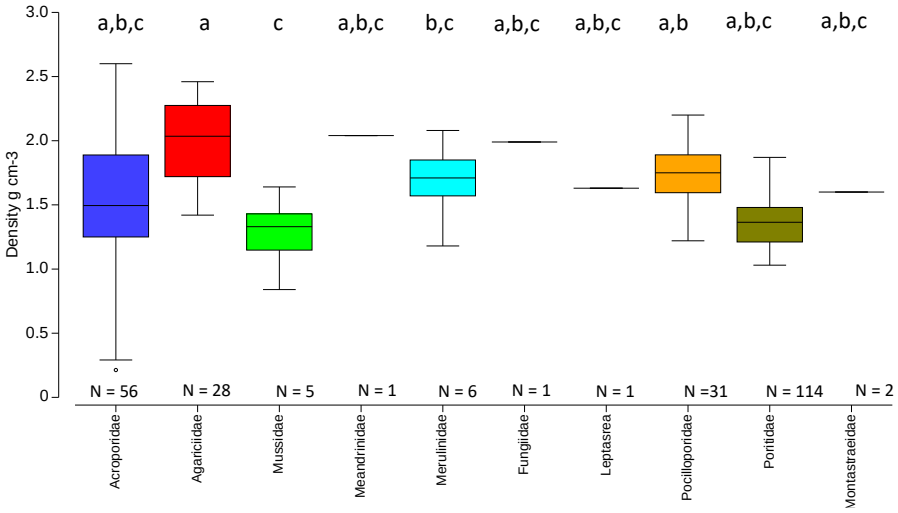
Skeletal Density according to Family

data extracted from 40 publications



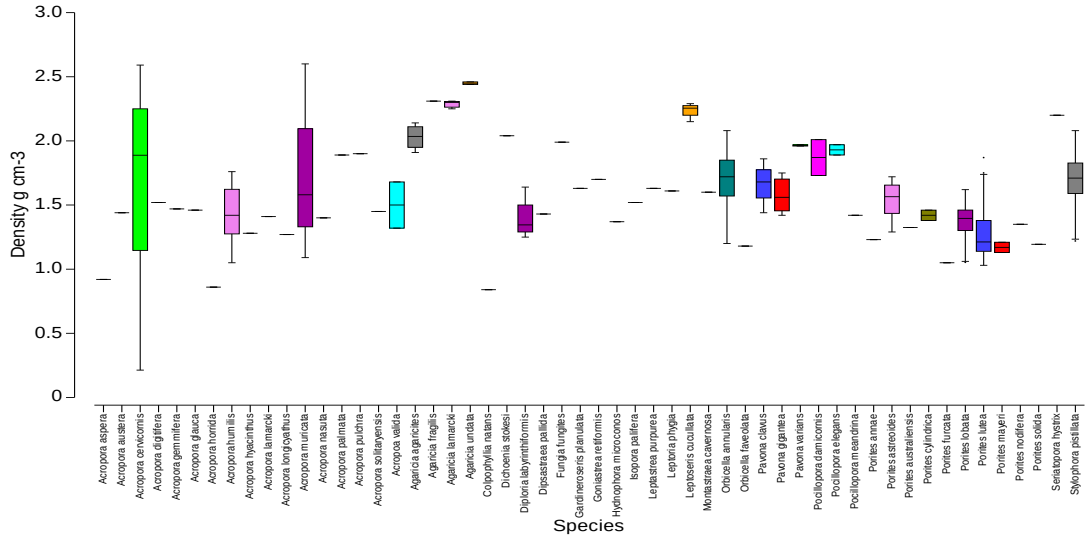
Skeletal Density (g cm^{-3}) according to Family

data collated from https://coraltraits.org/traits/61



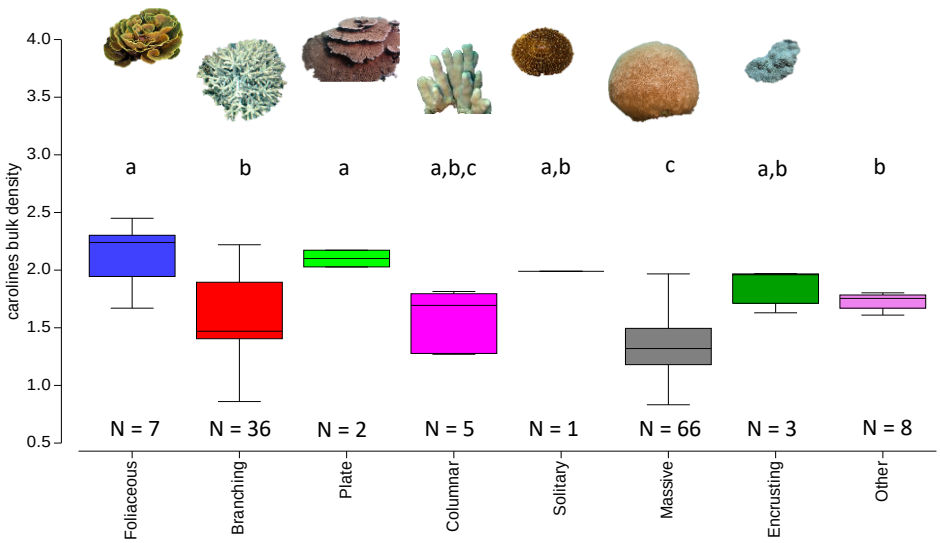
PRELIMINARY RESULTS

Variability within and between species



Skeletal Density according to Life Form

data extracted from 40 publications

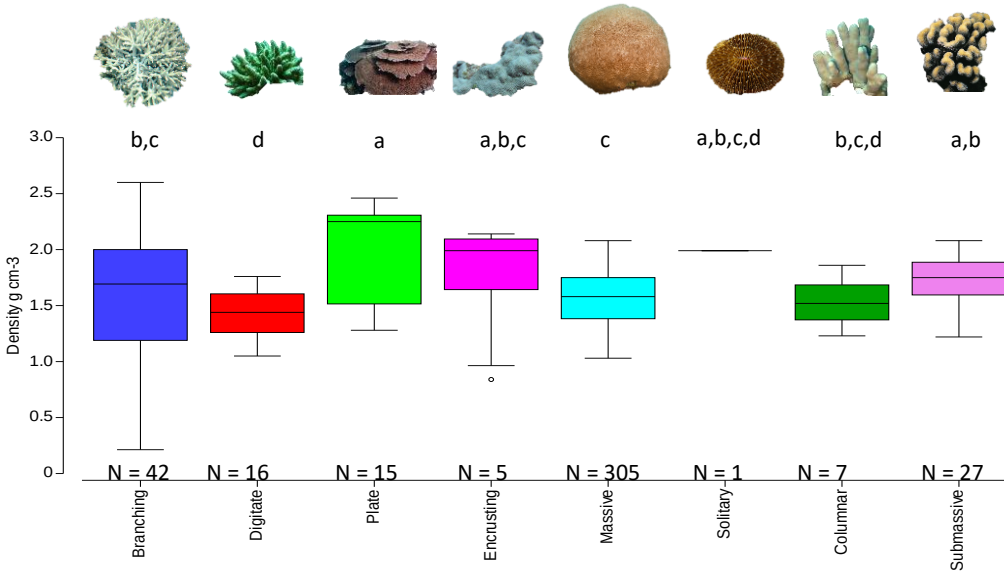


1) Foliose
2) Plate
3) *Solitary*
4) *Encrusting*
5) *Columnar*
6) *Branching*
7) Massive

PRELIMINARY RESULTS

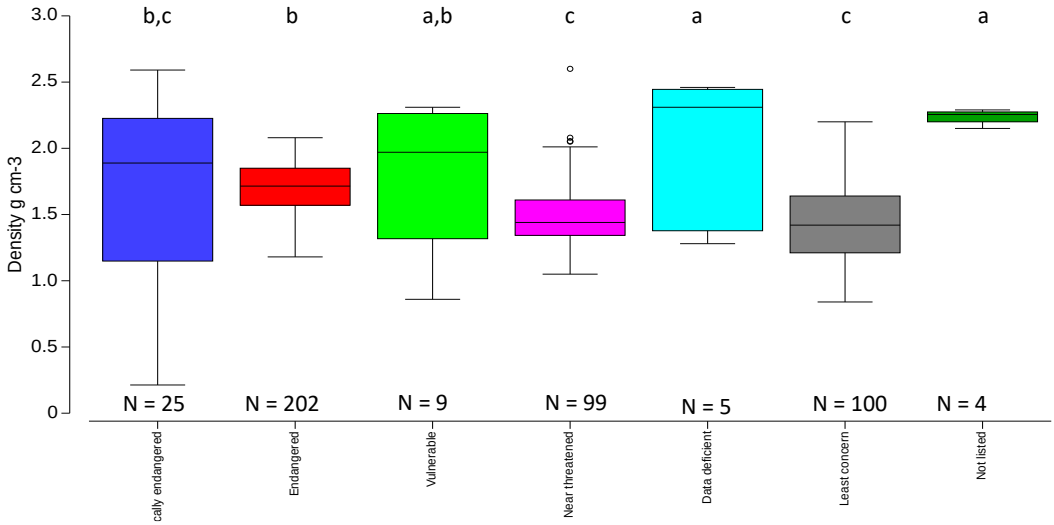
Skeletal Density according to Life Form

data collated from https://coraltraits.org/traits/61



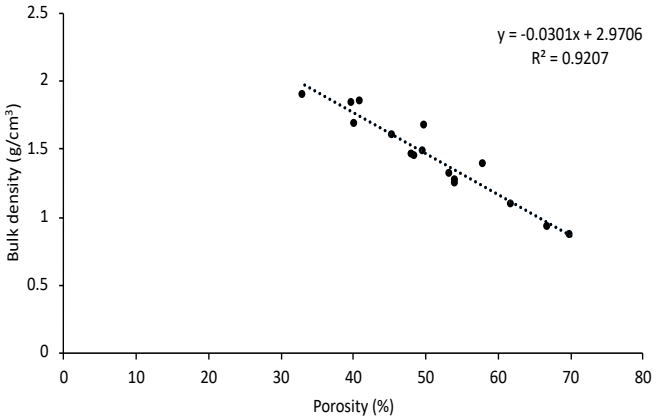
1) Plate
2) *Encrusting*
3) *Solitary*
4) *Submassive*
5) *Branching*
6) *Columnar*
7) Massive
8) Digitate

Coral density according to IUCN status



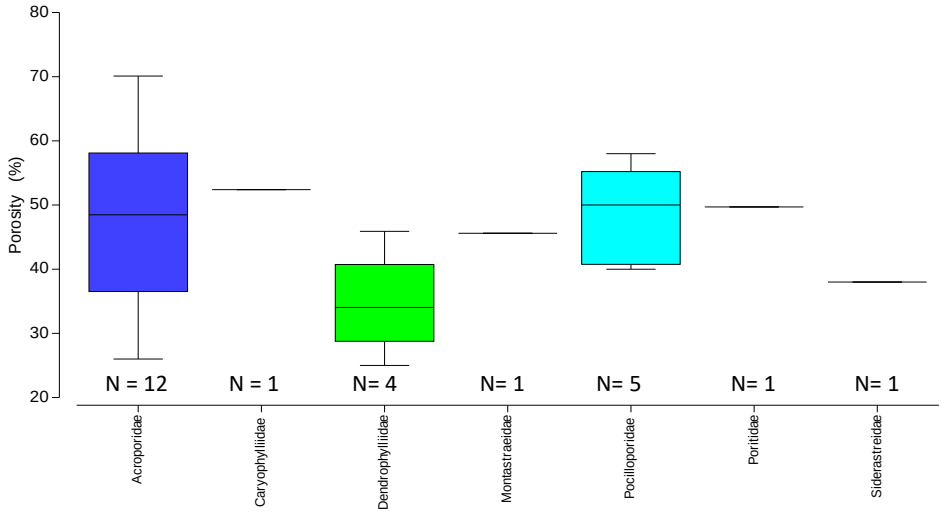
PRELIMINARY RESULTS

Correlation between bulk density and porosity



Porosity according to family

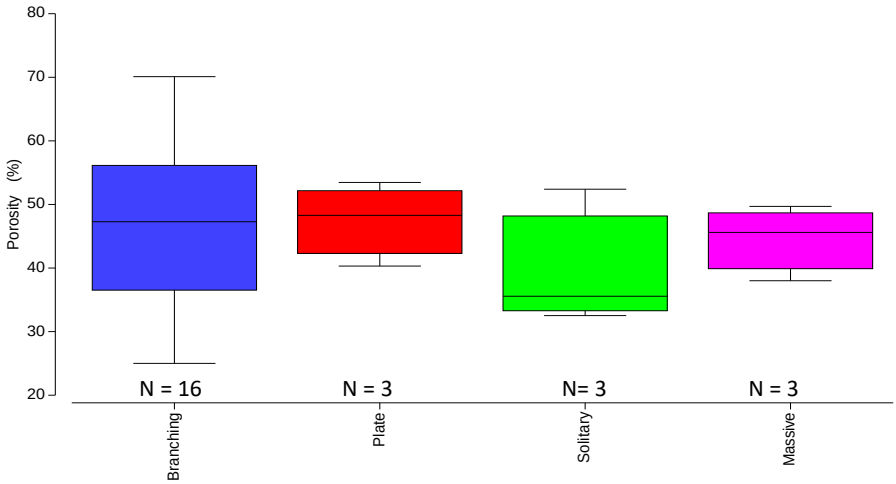
data extracted from 9 publications



PRELIMINARY RESULTS

Porosity according to life form

data extracted from 9 publications



Mechanical strength/ Breakage Point

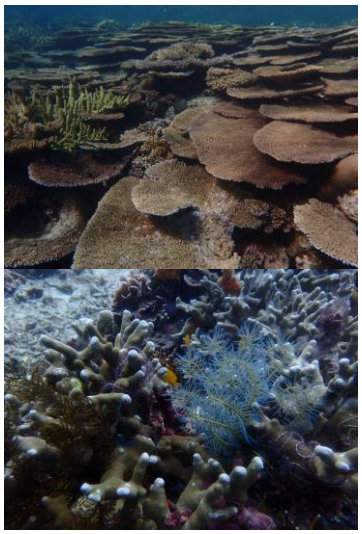
- Preliminary data (Osborne)
- Manual search "coral" and "skeletal strength" ~35 papers (not all relevant)

Table 4. Mean strength (MN/m^2) of Scleractinian coral in the context of ocean acidification

Norzagaray-Lopez *et al*. (2017) Skeletal dissolution kinetics and mechanical tests in response to morphology of coral general. *Facies* 63:7

Family	Genus	Species	Strength (MN/m^2)	S.D.	Growth form	Reference
Acroporidae	*Acropora*	*palmata*	47.7	± 17.3	Branching	Chamberlain, 1978
Siderastreidae	*Siderastrea*	*radians*	32	± 8.2	Massive	Chamberlain, 1978
Merulinidae	*Orbicella*	*annularis*	22.4	± 12.9	Massive	Chamberlain, 1978

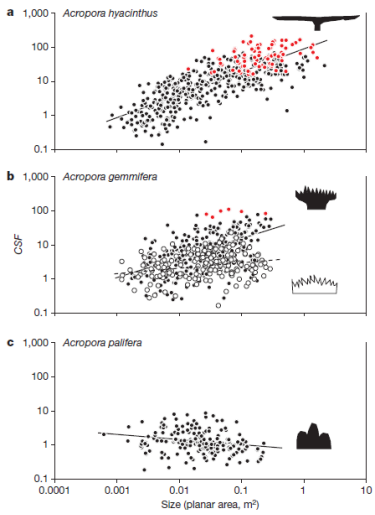
Variable coral thickness, surface area and fragility

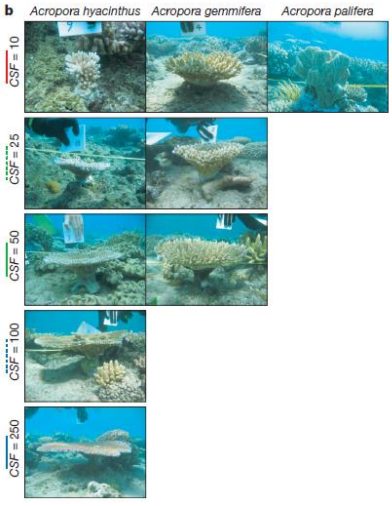


Colony size factor

Madin and Connolly 2006 Nature Letters: 44, doi:10.1038/nature05328

- Ecological consequences of major hydrodynamic disturbances





PRELIMINARY RESULTS

Vulnerability to breakage

- Not enough information available for many taxa

Structural form	Extension rate	Calcification rate	Bulk density	Porosity	Vertical/horizontal projection	Skeletal thickness
Branching	High	High	Low	High	High	Low - Medium
Digitate/Columnar	Medium	Medium - Low	Low	NA	Medium – High	Medium
Plate/Tabular	High	NA	Med - High	High (?)	Medium - High	Medium
Massive	Low	Medium - Low	Low	High	High	High
Submassive	Low	NA	Medium	NA	Medium - High	Medium - High
Foliaceous	Medium	High	High	NA	Low - Medium	Low – Medium
Solitary	Low	High	High	Low	Medium	Medium
Encrusting	Low	NA	Med- High	NA	Low	Med-High

Effects of ocean acidification on coral density and porosity

Caroline Osborne

Coral species	Exposure	Bulk Density	Porosity	Reference
Porites cylindrica	6 month mesocosm	No significant diff pH 7.74 vs 8.24	n/t	Georgiou et al. 2015
Stylophora pistillata	12 month lab	Yes pH 7.1 < 8, p <0.001	Yes pH 7.1 & 7.4 < 8, p < 0.05	Tambutte et al. 2015
Desmophyllum dianthus *Dendrophyllia cornigera*	11 month lab	n/t	No significant diff (11 mo) pH 7.81 vs 8.1	Movilla et al. 2014
Porites sp. *Favia* sp.	*In situ*	No sig diff pH 7.84 vs 8.05	n/t	Barkley et al 2015
Porites sp.	*In situ*	Yes pH 7.9-7.98 < 8.02, p < 0.001	n/t	Manzello *et al.* 2014
Porites astreoides	*In situ*	Yes pH 7.2-7.6 < 8-8.09, p = 0.0001	n/t	Crook *et al.* 2013

Effect of ocean acidification on mechanical strength/ breakage point

Norzagaray-Lopez *et al*. (2017) **Skeletal dissolution** kinetics and mechanical tests in response to morphology of coral general. *Facies* 63:7

Table 1 Mean (±SD) reaction rate constant (k), mineral content, skeletal density, and compressive strength of selected coral genera. Compressive strength tests were based upon four coral samples. Exposure period of time to acidic solution was 10 min, excluding *Pocillopora*, which was 20 min. The reaction order is also indicated ([a] = zero, [b] = first)

	Sample size	$k \times 10^{-6}$	Mineral content mg Ca g^{-1} coral	Skeletal density g $CaCO_3$ cm^{-3}	Compressive strength MPa
Pocillopora[a]	8	3.9 (0.9)	446 (103)	1.54 (0.15)	292 (59.7)
Porites[b]	16	569.4 (177.9)	378 (91)	1.32 (0.10)	191 (29.0)
Pavona[a]	3	9.4 (2.5)	301 (38)	1.24 (0.07)	2538 (498.4)
Psammocora[a]	3	2.7 (0.5)	367 (24)	1.50 (0.26)	–

Skeletal surface area influences vulnerability to acidification

Norzagaray-Lopez *et al*. (2017) Skeletal dissolution kinetics and mechanical tests in response to morphology of coral general. *Facies* 63:7

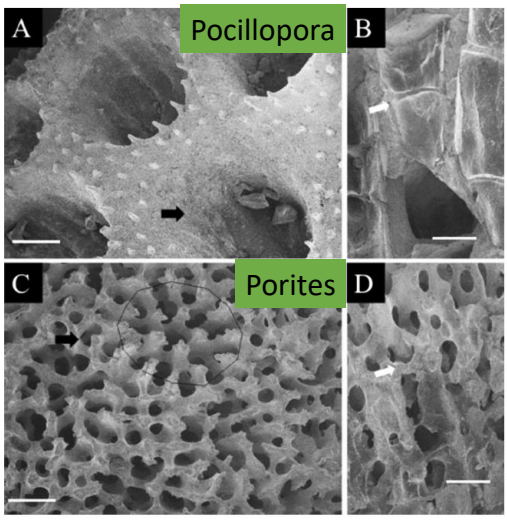


Fig. 7 Scanning electron microscopy images from *Pocillopora* (**a**) and *Porites* (**c**), where distinct calyx structures are shown (*black arrow*), while **b** and **d** images (*Pocillopora* and *Porites*) shows vertically oriented growth, where internal structures are depicted (*white arrow*). *Scale bar* 500 µm

polished

Exposed to acidifed water

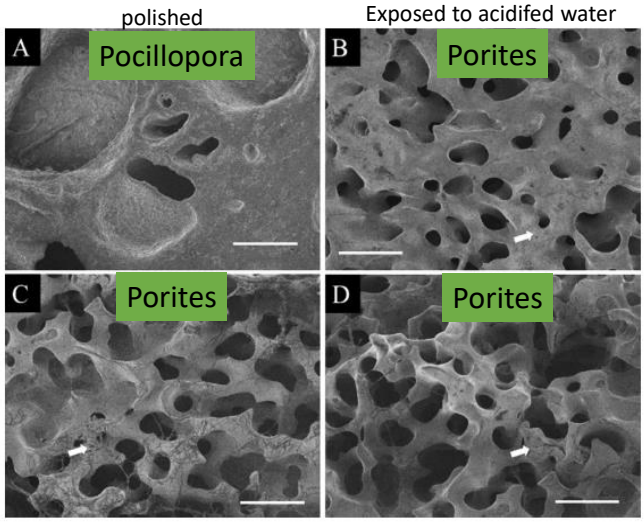


Fig. 8 Scanning electron microscopy images showing the surface area from *Pocillopora* (**a**) and *Porites* (**b**) polished samples. In figures **c** and **d**, successive dissolution stages of *Porites* skeleton after 10- and 20-min exposure to acidic solution are shown. Visible surface rugosity and semi-closed spaces in **b** has almost disappeared in **d** (*white arrows*). *Scale bar* 500 µm

Reef scale vulnerability

Higher sensitivity

- High diversity
- High vertical and horizontal structure
- High cover of porous, branching and plate corals

Lower sensitivity

- Low diversity
- Low vertical relief
- Mainly soft or encrusting and non porous hard corals

Major challenge

- How do we convert coral survey data into a reef vulnerability index?
- How should we "classify" coral?
  - Taxonomic (e.g. families)
  - Life forms?
  - Life form and colony size/shape?
  - Other?

https://www.apn-gcr.org/perspective/ocean-acidification-and-implications-of-the-covid-19-pandemic-for-the-scuba-diving-industry-in-four-regions-in-asia-pacific/

Perspective

Ocean acidification and implications of the COVID-19 pandemic for the SCUBA diving industry in four regions in Asia-Pacific

Long-term and short-term challenges for the dive industry

Authors

Kirsten Benkendorff, Roslizawati Ab Lah, Quach Thi Khanh Ngoc, Kay Dimmock, Inem Ode, Do Thuy Trinh, Gino Limmon

Date

25 January 2023

Project

Understanding the Interaction of Ocean Acidification and Marine Tourism for Sustainable Management of Coral Reefs

Introduction

Coral reefs are living structures built from the accretion of calcium carbonate. Ocean acidification is a chronic problem that influences the availability of carbonate ions required to build reefs (Figure 1) (Albright et al., 2018) and increases the risk of reef dissolution (Eyre et al., 2018). Ongoing decreases in pH are predicted under all future Earth System Models (IPCC, 2019). This could drive coral reefs towards their tipping point (Figure 1), with a net loss of coral and associated reefs

communities predicted to occur this century (Cooley et al., 2022). This will have serious implications for regional communities that are dependent on coral reefs for their livelihoods.

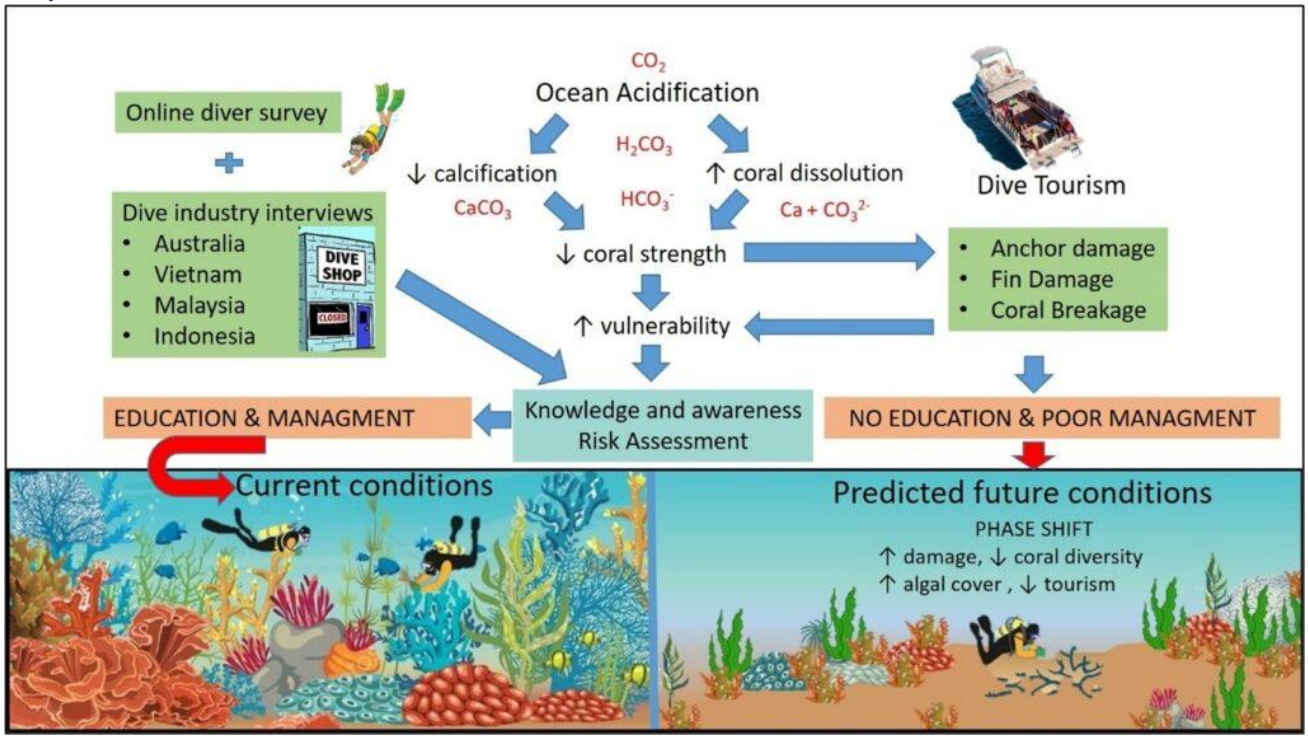


Figure 1: Conceptual model of the impacts of ocean acidification and dive tourism on coral reefs. An online survey of SCUBA divers, along with dive industry stakeholder interviews undertaken in four Asia Pacific regions were used to assess the state of knowledge on ocean acidification. This will feed into a risk assessment and inform the need for further education and management of coral reefs.

Ocean acidification is a complex scientific and management problem that will impact many Asian Pacific Nations that rely heavily on coral reefs for on marine-related economic activities (Cooley, Kite-Powell, & Doney, 2009). Southeast Asia is one of the world's leading recreational scuba diving destination (Dimmock & Musa, 2015). The combined effects of ocean acidification and marine tourism activities could place intense pressure on sensitive reefs and threaten their ecological and economic sustainability. As corals become more fragile under acidified conditions, their susceptibility to others forms of damage will increase. Dive tourism is known to have some negative impacts on coral

ecosystems, such as damaged caused through contact with the reef by boat anchors, fin kicks and poor buoyancy (Juhasz, Ho, Bender, & Fong, 2010; Noh, Shuib, Tai, & Noh, 2018; Praveena, Siraj, & Aris, 2012). The impacts from this type of damage is likely to be exacerbated under acidified conditions.

The combined effects of acidification and scuba diving on increasingly sensitive coral reefs requires effective management to ensure the protection of ecological, cultural and economic values. Managing the impacts of divers on coral reefs requires stakeholder engagement to implement non-regulatory strategies such as education. A study of stakeholder awareness of the importance of coral reef conservation in Perhentian Island revealed variable awareness and some denial of the damaging effects of snorkeling and diving (Saleh & Hasan, 2012). Improved awareness of the threat from ocean acidification could help engender a sense of stewardship in the dive industry , thus improving quality of pre-dive briefings and encouraging good dive technique. Effective education and leadership can encourage the necessary 'future oriented thinking" (Dimmock & Musa, 2015) for sustainable marine tourism in a changing world.

Awareness of ocean acidification in the dive industry

To assess the level of awareness of ocean acidification in the dive community, we undertook stakeholder interviews with Dive masters in four Asia Pacific regions: 1) Solitary Islands Marine Park, Coffs Harbour, Australia, 2) Hon Mun Marine Protected Area, Nha Trang, Vietnam, 3) Ambon Island, Maluku Archipelago, Indonesia and 4) Tioman Island,

East Coast Malaysia. Additional interviews were undertaken with Marine Managers in Nha Trang and Ambon (Table 1). An online survey was also distributed through social media networks and 67 SCUBA divers responded to the question “Before today, had you heard of Ocean Acidification?” We further divided these responses according to their level of dive certification and responses were further collated for divers with Australia, Malaysia or Indonesia identified as their country of origin (no Vietnamese divers completed the survey). Overall, we found an increase in the level of awareness of Ocean Acidification with higher levels of SCUBA dive certification and experience (Table 1).

The Solitary Islands Marine Park has a relatively small dive industry (4 commercial providers), and generally have good environmental awareness. Over 90% of Australian divers who completed the online survey were aware of ocean acidification (Table 1). Nevertheless, only 50% of the dive masters in the Solitary Islands Marine Park interviewed had prior knowledge of ocean acidification, although based on a small sample size (n=4). The two Australian Dive masters who were aware of ocean acidification identified it as a major threat to coral reefs. Furthermore, I the online diver survey, 9 of the 12 participants who specifically identified ocean acidification as a threat to coral reefs were from Australia, with a further two from the USA and the other with no identified country of origin.

Hon Mun Marine Protected area has rapidly grown as a popular dive spot in the last decade, with a burgeoning local and foreign tourist industry in Nha Trang. The Dive Masters and Marine Park Managers from this region report a high level of awareness of ocean acidification (89 and 90% respectively, Table 1). However, unlike the Australians, none of

the Vietnamese, participants defined ocean acidification or identified it as a threat to coral reefs. However, all of the Marine Park Managers and one third of the Vietnamese identified climate change, ocean warming or coral bleaching as a threat (Table 2).

Ambon Island has been identified as a high priority for biodiversity conservation in recent assessment of marine biodiversity in the Coral Triangle [16]. It is a relatively untapped area for dive tourism in a biodiversity hotspot, with just four commercial operators at the time of the surveys. None of the dive Masters (Table 1) or the Marine Manager interviewed from Ambon Island) had heard of ocean acidification prior to the survey, but the sole Indonesian diver who completed the online survey had heard of it (Table 1). Of the dive managers in Ambon, 57% considered climate change to be a threat to coral reefs in their region.

The Malaysia Islands are coral hotspots and have been identified as ecotourism destinations. Tioman Island is recognized as the most popular island for the tourism industry (Hanim & Redzuan, 2010). The dive Masters from this region showed a good level of awareness of ocean acidification (67%, Table 1), although none considered it to be a priority threat and only 37% identified climate change as a threat (Table 2). Similarly, 67% of Malaysia divers who completed the online survey were aware of ocean acidification (Table 1), but none identified it as a major threat to coral reefs.

Awareness of diver-induced damage and human impacts

The majority of stakeholders in this study considered the coral reefs in their area to be in a state of decline and identified various human

impacts as a major cause (Table 2). Only one of the Australian dive masters identified damage for diving or marine tourism as a risk, although diver induce damage has been previously reported from the Solitary Islands Marine Park (Hammerton & Bucher, 2015). Nevertheless, the relatively small number of marine tourism operators, strict regulations and high levels of education in Australia suggest these subtropical reefs are at lower risk from human activities than the other case study regions in the Asia Pacific.

Diving and tourism activities were infrequently identified as threats by the dive masters or marine managers in Nha Trang (Table 2). However, in a follow up question specifically asking participants whether they agreed diving and boating activities could have negative impacts, 44% of dive masters, but only 7% of Marine Park Mangers agreed. Nevertheless, the majority consider the reefs to be in decline as a result of various human activities (Table 2). A Reef Check programme has been implemented in Vietnam, which has demonstrated degradation of the coral reefs around Nha Trang (Long & Vo, 2013). Large boats of tourists focused around Hon Mun Island in particular could be contributing to observed coral damage and decline.

Diving or risks associated with marine tourism were not identified by any of the participants form Ambon and despite a range of human impacts that were identified, only 57% of these participants considered the reefs in this region to be in decline. This correlates with our observations of some incredibly diverse and pristine reefs on islands surrounding Ambon despite significant impacts in Ambon Harbour (Edinger, Kolasa, & Risk, 2000). The biodiversity value of these reefs, along with the limited knowledge of ocean acidification or potential for

diver impacts, leaves these coral reefs quite vulnerable to potential expansion of tourism in the region, without effective management. Unsustainable coastal development and uncontrolled tourism activities are thought to be causing to the declining of corals in Tioman Island (Shahbudin, Akmal, Faris, Normawaty, & Mukai, 2017). Indeed, a relatively high percent of Malaysia Dive Masters identified diver and tourism related damage as a problem (68% Table 2). However, most of these dive Masters appropriately commented that it was only a problem if done excessively and without precautions or training. A Reef Check programme has been implemented in Malaysia to facilitate marine parks management and diver education (Wetzelhuetter, Chelliah, & Chen, 2014). The outcomes of our survey are encouraging, supporting the positive impacts on diver awareness that can stem from programmes like this.

Table 1: Summary of the awareness of ocean acidification in the scuba dive industry and different cohorts of scuba divers in response to the question, “Before today, had you heard of Ocean Acidification?”

Stakeholder group	Yes	No	Percentage
Australian dive masters	2	2	50%
Nha Trang dive masters	16	2	89%
Nha Trang Marine Park managers	14	1	90%
Ambon dive masters	0	7	0%
Malaysian dive masters	13	6	68%
Scuba divers (online survey All)	46	19	71%
Australian divers	21	2	91%
Malaysian divers	10	5	67%
Indonesian divers	1	1	50%
Certificate level			
Open water	2	3	40%
Advanced	13	8	62%
Rescue/Research/Scientific/Tec 50	12	4	75%
Master	9	3	75%
Instructor/Course Director	10	2	83%

Table 2: The proportion of stakeholders that mentioned ocean acidification (or pH) and/or climate change in response to questions about the main threats[1] to coral reefs. This is compared to the number of stakeholders who referred to diver damage or marine tourism as a threat, or more generally, human impacts[2] and consider coral reefs as currently in a state of decline[3].

Stakeholder group	Acidification	Climate change	Divers/ Tourism	Human Impacts	Reefs in decline
Australian dive masters	2/4	3/4	1/4	4/4	3(minor)/4
Nha Trang dive masters	0/18	6/18	2/18[4]	13/18	15/18
Nha Trang Marine managers	0/15	15/15	1/15	15/15	14/15
Ambon dive masters	0/7	4/7	0/7	6/7	4/7
Malaysian dive masters	0/19	7/19	13/19	17/19	17/19
Scuba divers (online survey)	12/65	40/68	28/68	65/68	17/19

[1] The question about threats was open ended for the dive industry stakeholders, but for SCUBA divers in the online survey reference to climate change is take from responses to a question asking them to identify the top three significant threats to coral reefs, whereas reference to ocean acidification is taken from the same if specifically identified or responses to a question asking what they think about with respect to impacts of climate change on coral reefs. Climate Change encompasses ocean warming, global warming, rising temperatures and coral bleaching in the summarised results.

[2] Human impacts include diving, boating, tourism, fishing and pollution, but not climate change.

[3] Stakeholders were also asked about whether they considered the reefs in their region to be declining in health since they commenced diving and this is broadly categorised into yes or no responses.

[4] In an additional question specifically about potential for diver and tourisms impacts 8/18 diver Masters and 4/15 marine park managers answered yes.

Implications of the COVID-19 pandemic for the dive industry

In 2020, the progress of this project became significantly hampered by the global COVID pandemic. The borders of participating countries closed and most countries went into lock down. This restricted our ability to travel to undertake stakeholder interviews, but is likely to have had an even more significant impact on the livelihoods of many stakeholders in the dive industry due to a cessation of international tourism and temporary drops in the domestic market. However, the length and magnitude of impacts is likely to have varied between countries (Table 3).

In Australia, the borders were closed to international tourists for 2 years. However, complete lockdowns were relatively short, thus allowing domestic travel, at least within states and territories for most of this time (Table 3). The Government also provided financial assistance to impacted businesses and employees during lockdown and schemes to promote domestic tourism to reignite the economy after lockdown. The Australia dive industry stakeholder surveys were conducted early in 2021, after the first lockdown, whilst some border restrictions were still in place, which made it difficult to find participants. Two of the four Australia Dive Masters noted impacts due to COVID in the surveys; one mentioned fewer boats and divers and another indicated more “red

tape" and getting harder to do the right thing and be financially viable. Interestingly, one commented that COVID might cause more people to look within the state of NSW for diving and one explicitly stated they didn't close during (the first) COVID lockdown. Two mentioned that whale watching and diversity have contributed to the viability of their businesses in these difficult times. Overall, the Solitary Island dive industry was impacted by COVID-19 but is relatively resilient.

Vietnam reopened its international border in March 2022, two years after it had been closed to foreign travelers (Table 3). Diving activities in Nha Trang attract mainly international tourists. Prior to the Covid-19 outbreak, the majority of foreign visitors to Nha Trang (roughly 70% of all visitors) came from China and Russia (VNExpress, 2018). However, China hasn't really opened up to allow its citizens to travel abroad until recently. In addition, the prolonged war between Russia and Ukraine made the ruble depreciate, leading to a significant decrease in the number of Russian tourists to Nha Trang as well as Vietnam (VietnamFinance, 2018). Therefore, Nha Trang's tourism industry has yet to recover from the COVID 19 pandemic. Only a small portion of the scuba diving industry is active; many scuba diving businesses are still closed and unsure of when they will reopen. Of the 24 SCUBA dive companies in Nha Trang that were advertised online before the pandemic, only 8 appear to be active with postings about dive events within the last few months. One company explicitly states that they have now closed due to lack of divers and the others haven't posted since 2019 or have websites that no longer work.

In Indonesia, international borders were closed for one year, however, there have been lockdowns restricting movement on a local scale in

some provinces due to higher and lower infection rates in the population (Table 3). Furthermore, in April 2020, all diving tourism activities were stopped, and people were not able to travel to areas to dive due to a government policy implementing restrictions on community activities in an effort to stop the spread of the corona virus. The dive industry in Maluku province was heavily impacted due to lack of international and domestic tourists and all of the diving centers closed during the ppandemic. However, starting in March 2022, the Indonesian government, eased domestic travel restrictions. Domestic and foreign tourists are now returning, despite the ongoing Covid-19 pandemic. It may take a while for the dive industry to recover in more remote areas like Ambon and Banda Island. However, some of the divers surveyed online did indicate preference for low tourist areas. This could be used as a niche marketing incentive to attract higher paying environmentally aware SCUBA divers interested in a safe diving holiday in a pristine location.

To combat the COVID outbreak, the Malaysia government implemented Movement Control Order (MCO) from March to May 2020 (Table 3). During MCO, any mass gathering and outside movement other than purchasing necessities such as buying food or medicine were prohibited. Further, the MCO was replaced by the Conditional Movement Control Order in June 2020 where the economy was reopened in a controlled manner. However, education sector including universities remained closed in Malaysia. Complete total lockdown was implemented in June 2021 (Table 3) resulting in delaying the project survey. The surveys of dive stakeholders in Malaysia were only able to be conducted in October 2021 after extended total lockdowns had

lifted. These surveys asked for pre-Covid responses and did not specifically ask any questions about COVID-19 impacts. None of the Malaysia diver masters mentioned COVID-19, however five out of 9 Dive shop managers identified it as a challenge. The issues identified included travel restrictions on local and international travelers, lack of medical facilities, struggling with unstandardized COVID-19 SOPs, Government intervention and controls, financial struggles and generally struggling to survive the Covid-19 pandemic.

Table 3: Summary of border closures, lockdowns and government assistance in response to the COVID-19 pandemic

Country	International border closure	Months of local lockdowns	Government assistance
Australia[1]	24 March 2020-March 2022	April – July, 2020 then state/region dependent including Aug-Oct 2021, then state/hotspot dependent.	COVID payments for impacted businesses and employees, early access to superfund scheme, regional stimulus packages and free vaccination.
Vietnam	March 2020-March 2022	March – April 2020 (countries lockdown), July - September 2021 (local lockdowns).	Social security package of up to $US 2.6 billion with specific support for the poor and workers who lost their jobs due to the COVID-19 epidemic. Tax exemption and reduction of fees to support the recovery of businesses, cooperatives and

			households after the COVID-19 epidemic, support for union members and employees affected by the COVID-19 epidemic.
Indonesia[2]	2 April 2020-2021	April-June 2020, lockdown in several provinces, then restrictions on community activities and social distancing since January 2021 in hotspots areas to prevent spread.	Yes – cash transfers for impacted people, relief in credit payments for informal workers, provide tax incentives and free vaccinations.
Malaysia	18 March 2020 – April 2022	Movement Control Order in March to May 2020, Conditional Movement Control Order from May to March 2021, Total lockdown June 2021.	Yes, COVID-19 payments for impacted businesses and employees, bank loan moratorium, educational loan repayments deferred, free vaccination, daily free 1GB internet.

[1] Department of Employment and Workplace Relations. COVID-19 timeline. Years, Months, Dates City/Town State/Territory Event https://www.dese.gov.au Australian Government

[2] Ministry of Public Works and Housing of the Republic of Indonesia. Handling the covid -19 pandemic. https://setjen.pu.go.id/birokeuangan/index.php/penanganan-pandemi-covid19

The online diver survey was undertaken in early late 2021- early 2022 when some countries were still in lockdown and/or with border restrictions. In response to a question on whether COVID has influenced the way they will choose dive sites in the future, 33 respondents (60%) indicated “yes”, 2 were unsure and 20 indicated “no”. The reasons given by the two indicating ‘no’ were 1) they are vaccinated and don’t go into populated areas anyway and 2) they had decided some years ago to dive locally to reduce their carbon footprint. Of those who indicated yes, the most common reasons were around border or travel restrictions (14) or safety and the risk of infection (13); nine participants identified case numbers in the region and vaccination status of the country and influencing factors; a further four participants identified issues around sanitary measures implemented by the operators. Five participants specifically indicated that they would seek out sites that were less crowded or with fewer divers and/or would avoid sites with mass tourism. Seven participants indicated other issues around travel, including increased costs of travelling and travel insurance and disrupted travel plans. Two participants indicated they were now keen to travel to places they had postponed in the past, whereas another two had reflected on the environmental costs of travel during lockdown and were less likely to travel far. Overall, these insights suggest that there may be increasing demand for boutique diving operations at locations with high quality coral reefs, with few divers and good sanitary methods.

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