Allen Coral Reef Atlas: Use Cases Leveraging Coral Reef Big Data and Visualization to Inform Global and National Policy

Eric Welch, Lesley Michalegko, Yidan Zhang, Shaika Islam, and Elizabeth Corley
Center for Science, Technology and Environmental Policy Studies (CSTEPS)

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I. INTRODUCTION

Coral reefs are home to a large share of global plant, animal and microbial biological diversity. Coral reefs are continuously under threat of destruction and loss from rising temperatures, fishing and shipping and the land to sea, or ridge-to-reef, impacts. Recent global efforts to establish new commitments to reduce marine biodiversity loss have largely failed (Mongabay, 2021; CBD 2021; Reuters, 2021; Sala, 2021) due to the significant social, economic and ecological complexity underlying the primary causes of biodiversity loss, including that of coral reefs. The Allen Coral Reef Atlas ('Atlas') was developed, at least in part, to help monitor one part of the marine environment – shallow tropical coral reefs – as means of better assessing global reef health and providing information that could benefit conservation and management efforts.

Atlas has already been used as a bridge between science and decision making. For example, it has been applied to marine spatial planning activities in Vanuatu, Samoa and the Arabian Sea, among others. Yet, the current challenge is to expand the applicability and usefulness of Atlas big data for decision making at multiple scales – local, national, regional and global. To do this, the organization is seeking ways to move beyond a science and data driven approach, to better connect with user context. In particular, Atlas is seeking ways to better inform decisions and policies on the land in ways that improve the health and conservation, of the reef. Key questions include:

- What are the ridge-to-reef challenges facing communities, organized stakeholders, government and other decision/policy makers?
- In what ways could better data, new measures, and new insights facilitate management and governance of ridge-to-reef protection?
- What are the current challenges related to accessibility and usability of Atlas data for stakeholders?
- What strategies could Atlas take in the future to increase its ability to inform ridge-to-reef decision making?

This report presents findings from a small study on the potential directions Atlas could take to better connect to the user context. Report contents reflect a summary of information gleaned from interviews with marine managers, marine biologists, social science scholars, and other policy makers, supported by findings from a literature review. The report is organized in several sections. We first present our use case approach and framework, including a brief discussion of ridge-to-reef challenges and a simplified orientation to the policy and governance context. We then present six use cases that address the current shortcomings and potential future opportunities that lie ahead for Atlas. The use cases are intended to inform Atlas overall, rather than point to a particular metric or reef community. Our intention is to stimulate a broader discussion about the usefulness and accessibility of big data for social information and intervention.

II. RIDGE TO REEF: FITTING THE OPPORTUNITY OF ATLAS WITH THE CHALLENGE OF GOVERNANCE

Key threats to coral reef health are associated with multiple anthropogenic stressors from land and sea. Land-based stressors, such as deforestation, soil erosion, runoff, and sewage can result in sedimentation, poor water quality and disrupted nutrient cycles. Sea-based anthropogenic stressors could include overfishing, poaching, physical damage, contamination from spills and sea-based pollutants (Klein et al.2012, Hughes et al., 2018). These human generated stressors, in addition to rising ocean temperatures and acidification due to climate change, are leading contributors to deterioration of marine ecosystem health, including the vitality of coral reefs. Figure 1 presents a simple schema of the ridge-to-reef concept and context, in which human development and activity on land has a downslope effect on the coastal environment. Not visible here are the numerous ecosystem services that directly and indirectly benefit land-based human societies.

Figure 1. Ridge to Reef Schematic
Source: Climate Media Factory

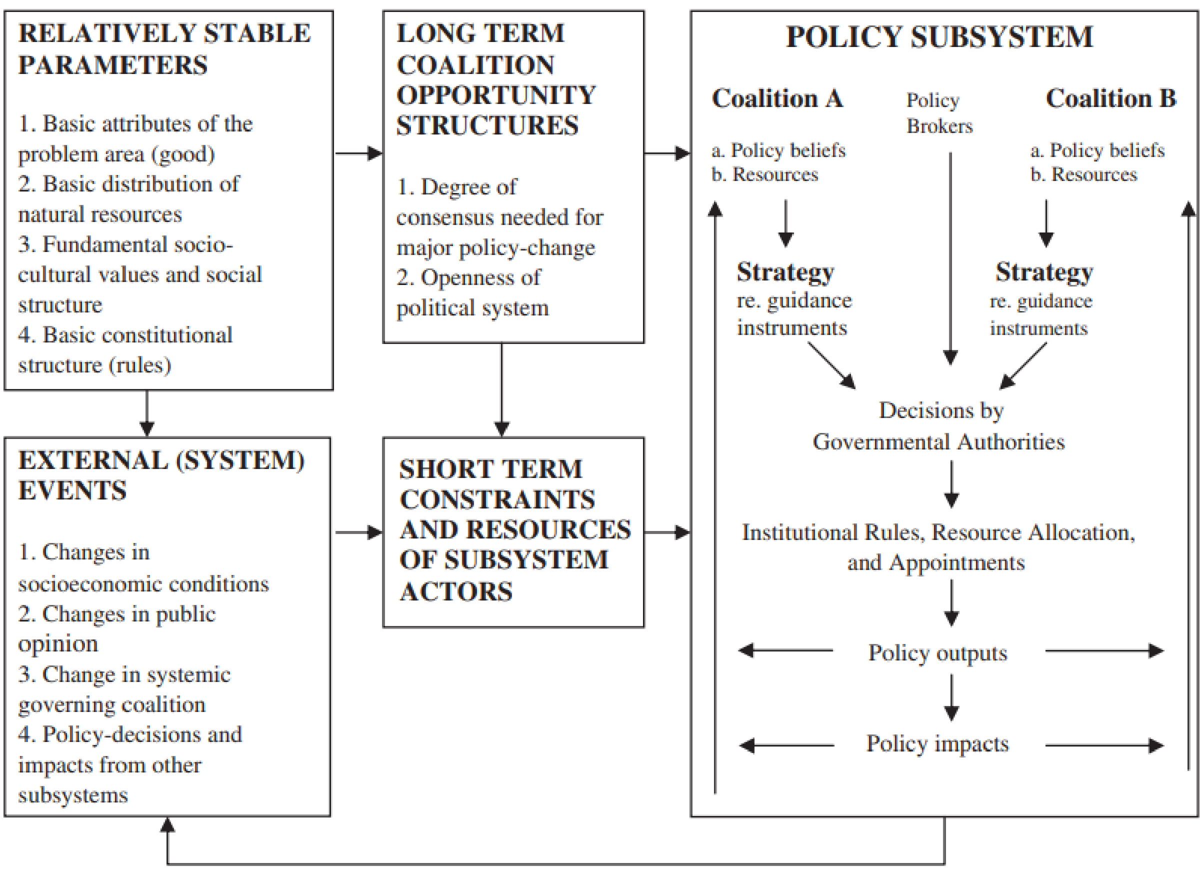
Evidence suggests that reducing destructive land-based activities such as deforestation or increasing the protection of forest areas, can significantly improve the coral reef health (Klein et al. 2012; Rude et al., 2016; Suárez-Castro et al., 2021). Entire research programs – such as the Coral Reef Ecology Lab at the Hawaii Institute for Marine Biology and the University of the Virgin Islands Ridge to Reef ESPCoR Project – are demonstrating how land-based human activities have negative effects on reef health. Much of this work aims to inform the management, policy and practices that protects terrestrial, coastal and marine habitats to minimized potential impacts at the shoreline interface (Adams and Possingham, 2017; Delevaux et al., 2018). For example, mangrove restoration projects in Colombia, Philippines, and the US Virgin Islands, to name just a few, are intended to improve habitat for marine organisms and water quality, among other benefits that ultimately have positive impacts on coral reef conservation (Hapinat, 2019; Project interviews conducted by CSTEPS).

Yet the complexities of land to sea extend well beyond the natural systems and corridors that are so frequently the focus of academic research. Societies that inhabit the ridge range differ significantly in history, culture, institutions, values, beliefs and capacities. Additionally, the scale of the human component is enormous. According to UN-Oceans (2011), approximately 44 percent of the global human population lives within 150 km of a coastline. Human systems are structured and ordered, such that they design plans and establish policies that proscribe behavior. Yet they are also politically fragmented, have conflicting priorities, and vary in their willingness or ability to invest capacity (human, financial, etc.) in ridge to reef solutions or carry through with decisions. Even in the US Virgin Islands, a relatively well-resourced example, the capacity to organize disparate groups to generate plans and commitments to reducing the impact of land on protected reefs is highly limited (Project interviews conducted by CSTEPS).

Decision Context at the Land-Sea Interface

The decision context at the land sea interface include multiple participants with varying interests. For example, in addition to local government officials, participants could include farmers, government transportation planners, private sector lumber companies, tourism industry, and sewer and stormwater regulators, to name a few. The formal policy process in most localities, countries and regions is well understood to be slow, non-linear and subject to influence by well-established stakeholders. Moreover, the policy process includes multiple stages – agenda setting, policy formulation, implementation, monitoring and enforcement. At each of these stages, a particular policy is subject to feedback, competition with other policies, political intervention, revision and varying levels of commitment and capacity. For illustration purposes, we have reproduced a self-explanatory schematic of a well-accepted theoretical framework for depicting the policy process and the relevant policy actors in Figure 3.

Figure 3. Advocacy Coalition Framework



Source: Sabatier, et al.

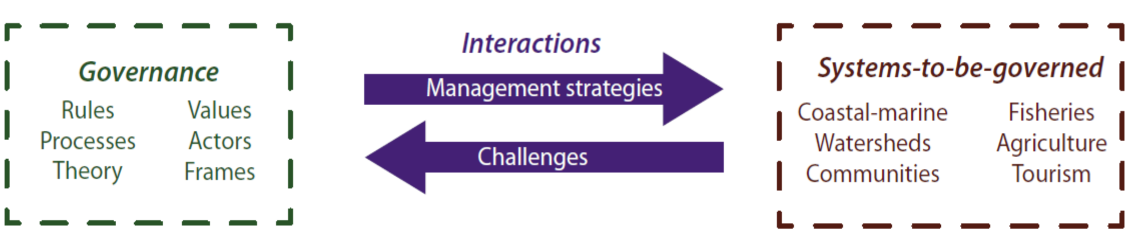
While we do not discount the value of formal policies as interventions that can occur to improve reef conservation and health, we also believe the formal approach to policy should be tempered. Recent work by Amelia Wenger is showing the substantial diversity in approaches to planning and governing the ridge-to-reef, and that while there are some commonalities across coastline management, the results clearly demonstrate that coastline management plans and policies are diverse and are subject to the complex social and political processes described above. Because harmonization of these efforts across the multiple administrative and cultural divides that may exist on the ridge of a large marine ecosystem is sometimes prohibitive based on capacity and resources, it is best to turn to other models that are more consultative, cooperative and focused on bringing multiple groups together in legitimate decision forums. It is in this context that the term governance most commonly replaces formal policy, and where the use of big data such as that provided by Atlas can offer insights and lead to sustainable decision outcomes.

Governance of the land sea interface is a perhaps one of the keys to effective conservation of the world's coral reefs. Governance can be defined as the formal and informal processes and institutions that influence collective activities. Governance implies networks of actors – government agencies, private firms, industry associations, universities and other research institutions, nongovernmental organizations (NGOs), professional associations – that design, develop and implement rules, processes, expectations and commitments, sometimes without formal governmental authority (Keohane and Nye, 2000).

At the coastal interface, governance is necessary to enable effective regulation and management of complex socio-ecological systems (Singh et al., 2021). But it is challenged by the multiplicity of jurisdictions on land that are often (1) locally specific, developed over a long period of time, (2) comprised of nested and overlapping sets of social systems with different traditions, jurisdictions, and authority structures, (3) poorly aligned with ecosystem or administrative boundaries in the sea, and (4) subject to rapid change (Adams et al., 2014; Álvarez-Romero et al., 2011; Cheong, 2008; Cinner et al., 2012; Henocque, 2013).

While a legitimate system of governance generally promotes inclusive decision making (Álvarez-Romero et al., 2011), the size and scope of the land sea interface creates enormous challenges to inclusivity and coordination. Moreover, research has generally focused on dimensions of the natural system (Christie, 2011) not on the governance of social and institutional systems. Failure to systematically address the governance challenges will result in further fragmentation, inequity and vulnerability for decades to come. Figure 2 presents a simplified schema of the role of governance for land to sea systems.

Figure 2. The role of Governance in Land-Sea systems (Source: Pittman and Armitage, 2016)



The Importance of Big Data for Governance and Management of the Land Sea Interface

Given the complexity and fragmentation of the land-sea interface, big coral reef data may be an important component of governance "co-creation" in which local key actors work with data experts to identify the most pressing land-sea issues and deliver credible, evidence-based input for local decision-making. Localities operate on norms, expectations and power structures that often constrain ideas and behaviors, marginalize alternatives, and reinforce social and cultural biases. Co-creation integrates data and information needed to reconcile conflicting perspectives, approaches, and understandings to enable informed regionally aligned policy solutions. This approach, while perhaps less straightforward than a formal, top-down policy intervention, offers several benefits, including increased flexibility for change with new information and potential for more buy-in from stakeholders who are actively involved in the development of policy solutions. Additionally, because the process of co-creation is dependent on working with multiple stakeholders towards a common goal, there may be more opportunities for influence and impact at multiple stages of the policy making process. In the use cases that follow, we outline some of these potential opportunities for big data interventions to influence decision making at local, regional and global scales.

III. USE CASE APPROACH

Increasingly organizations are aggregating and producing large amounts of data, often for the purposes of scientific research, monitoring and observation, or other reasons. Much of this data is natural systems data (atmospheric, biological, oceanic, etc.). While these datasets are often actively accessed, shared and used by members of the science community, the value and insights the data and analysis provide to policy, planning and management are often unrealized or underutilized.

Data use cases represent one tool for conceptualizing ways in which the investments in big data research may be harnessed, including for policy, planning and management through activities that engage stakeholders, publics and decision makers. For the purposes of this project, we define the term "use case" as a specific insight into ways that Atlas can leverage the data it collects for greater local, regional or global use and impact. High quality data use initiatives are those that have important impacts such as increasing the awareness of key actors, changing perceptions about the linkages between human and natural systems, altering behaviors, adjusting weights on parameters for policy and decision making, and ultimately changing policies, plans and societal practices.

Use cases are more effectively advanced when they are developed within a conceptual framework. For example, not all use cases are viable interventions at all stages of the policy or decision-making process (e.g. data4policy). Similarly, use cases should recognize that presentation and analysis of big data occurs within a social context. It is not enough to assume that a simplified visual presentation of complex natural system has similar meaning across all actors, or even similar actors across different locals. Therefore, to effectively leverage big data, a use case must recognize the variability of the social context in which the data intervention has an impact on individuals, groups, organizations, networks or broader aggregations of people. Similarly, big data use cases must consider the capacity of the user to access, manipulate and analyze complex data.

Framework for Generating Use Cases for Ridge to Reef

As part of the project, we developed a use case framework from which we could justify inclusion of specific use case examples. The framework, which provides a structure to communicate and critique the use cases, has five components:

1. Identifying the policy or governance related problem. For each use case, it is critical to first identify the specific challenge that Atlas must either overcome or that Atlas data can inform. Our approach is primarily from the user (human/society/decision-maker) perspective, rather than from the ecology/environment perspective. For example, the issue may be the extent to which Atlas effectively communicates with decision makers, or the extent to which reef data must be expanded or enhanced to better inform complex decision processes.

2. Articulating the specific use case. This step includes a brief description of the use case, its scope, potential stakeholders / users, and the decision context(s). The scope of the use case could be geographically specific (local or community level) or broader (national, regional, global). We provide a brief description of the policy process to highlight one means of identifying the point of greatest relevance for the use case.

3. Potential impact. In what ways will access and use of big data through some form of intervention address the policy problem? Will it fill an information gap? Will it generate new understanding of the policy problem? Will it generate a potential solution to a problem?

4. Use case detail. This step of the process involves describing the components of the use case including design, data used, relevant stakeholders, specific activities, mechanism of impact. Specific activities could include data integration, training modules, modeling efforts, communication and messaging (among others). The mechanisms of impact might address how the use case will have an effect, including some expectation of cause/effect linkages. For example, a mechanism of impact could be to improve communication about how deforestation can cause increased turbidity or how bleaching may increase the sense of risk associated with excessive logging. These activities could then be linked to long term economic costs, which will also affect perceived risk.

IV. ATLAS USE CASES

Summary of Suggested Directions

1. We suggest that Atlas products and approaches should be better communicated and better developed from a user perspective. Since Atlas is a large dataset and the accompanying documentation is technical, users might not find them universally accessible. Additionally, the science communication literature finds that transparency about limitations of data is essential for trust. Atlas has strong applications in the Global South; yet, countries in this part of the world might not have the technical capacity to work with the dataset without training. Some of these accessibility and usability challenges could be remedied through a more detailed service orientation or through re-tooling certain activities toward co-production to simultaneously meet the user needs and Atlas interests. We emphasize that this is less about anticipating data platform content and more about engaging users to determine co-production goals, governance and policy context and challenges, and data, skills and documentation needs. In addition, it is important for users and decision makers to know what Atlas includes, but also what it does not include in a very transparent way.
2. We suggest that Atlas continue to explore connections between the reef data and other relevant datasets, but to give priority to integration of human systems and socioeconomic data. Given that policy decisions are tied to jurisdictions, Atlas data could be particularly useful for decision makers if it included administrative and policy boundaries. Atlas has started pursuing this somewhat with integration of global MPA data set and maritime boundaries (EEZs), but needs to be more robust and connected to boundaries on land. With this addition, the reef impacts (such as turbidity, silting, pollution) could be more easily attributed to ridge associated decisions and development trajectories in certain locales (e.g. logging, disease, urbanization). If the administrative boundaries and linked socioeconomic data were included with the natural systems data, it would be easier for decision makers to determine, for example, who are the stakeholders responsible for mitigating any negative side effects of runoff, or what ridge tradeoffs operate to constrain reef conservation.
3. We suggest that Atlas invest in one or two stretch application efforts to capture human systems data – such as roadways or building footprints – to further articulate the corridors that link human and natural systems from ridge to reef. CSTEPS has invested in hiring a GIS student to merge Atlas data with multiple other human system data layers to link ridge to reef in a particular locality. Data layers include infrastructure (buildings and roadways), sewers and water treatment, tourism and other economic parameters, mangrove forestation, deforestation, nitrogen effluent, and many others. Additionally, we intend to work with the locality to investigate complementary local sources of data, governance and policy challenges, stakeholder diversity, and potential co-production opportunities with local actors.

Atlas Use Case 1: Science communication, transparency, data access and accessibility

Policy challenge: Limited uptake of existing Atlas data and information by policy and decision makers at all levels due to poor and ineffective documentation, transparency and communication.

Articulating the Use Case: Improve Atlas transparency and access. Effective science communication requires transparent disclosure of the specific value and limitations of the data system, as well as clear examples of application (Olesk et al. 2021). Open availability data does not equate to accessibility of data. It is important to move well beyond the current open-data approach to recognize that openness is only beneficial if the data are usable at the point of decision making. Demonstration of applicability at multiple governance scales (local, regional and global), and to different stages of the policy and decision-making process are important for further uptake. Similarly, greater accessibility enables feedback from users for improvements in the platform.

Potential impact: Atlas could substantially increase its policy and governance impact in shallow reefs contexts in the Global South, places with vulnerable marine ecosystems, and where the ridge is undergoing substantial economic development and decision makers may not have the technical capacity to effectively use the data for decision making.

Use case detail: Scientists often approach science communication from the perspective of a 'deficit model' which advocates that more information will improve rational action and policy making. This model has been substantially discredited (Ahteensuu, 2012). Instead, the science communication literature recommends a demand orientation: targeting science products to users (or audiences) and contexts in ways that directly meet needs (Longnecker, 2014).

Two main subcomponents of effective science communication are transparency and access. Transparency is the clear communication of the contents and limitations of the scientific and technical content. For Atlas, transparency is an important principle for fostering trust with users, which is an essential determinant of use. Access is the extent to which technique, technical information and data can be readily taken up and used. Data openness – providing data in an open repository that allows download, or providing functionality on the website – does not necessarily mean the data are accessible. The aim of many large science-based data systems is to be open for research. Large data visualization efforts often consider 'openness' to mean that data are downloadable or that code is available on Github. While FAIR data principles (https://www.go-fair.org/fair-principles/) are relatively well accepted in the sciences, data systems vary to the extent that they consider access for users with different capacities.

After working with the Atlas data for several months it is clear that findings on transparency from the science communication literature (Pielka, 2007; Weingart and Guenther, 2016) can be applied to: (1) enhance utility for current users, (2) better incentivize use in contexts with limited data analytic capacity, and (3) create opportunities to build capacity for use of big data for complex decision making. Atlas is not transparent about the limitations of its data. For example, because Atlas is useful only for 15m depth shallow reefs it is not clear what proportion of critical geographies are actually covered by Atlas. Are there reefs, localities, MPAs, countries or regions that are particularly well covered by Atlas data? If Atlas is not useful for some countries or some reefs because of poor coverage or resolution, then that needs to be clearly articulated in Atlas communications (e.g. website). Additionally, it is fairly common practice and, in some cases a legal requirement, for geographic data sets to include explicit disclaimers about the limitations of their information: https://www.gisagmaps.com/legal-disclaimer/. While Atlas limitations are outlined in the FAQ section of the Atlas website, it is recommended that disclaimers are also covered on the Atlas landing page or at least some mention of limitations exists within the Atlas mapping interface itself.

Additionally, our understanding is that the Atlas project does not fully recognize the variable levels of proficiency across potential users who could access and use the data. While the Atlas website provides documentation on science and methods, these resources appear to be targeted for use by researchers who already have significant analytical skills and substantial background knowledge. Improving the way in which Atlas communicates with intended audiences (local to global policy actors and stakeholders) who may or may not have training in marine science or data analytics, could increase use and impact. Because the science communication literature recommends testing products and messaging with intended audience to confirm salience (Bruine de Bruin and Bostrom, 2013), Atlas may want to review revised documentation with user groups. This type of engagement could present additional opportunities to Atlas for future development and co-creation of data products.

These two observations – need for transparency and access divide – represent important overlapping barriers to the use of Atlas data. Atlas could greatly improve the uptake of its data if it focused on its primary user community, increased transparency of its communication, and enabled better accessibility to the data. For example, the value of Atlas data may be greatest for lower income countries in the Global South that do not have effective reef mapping and monitoring capacities. Countries in the Global South also have lower capacity to use the data. Additionally, the desire of Atlas to have greater impact globally comes into conflict with local efforts or initiatives developed by international NGOs, for example. Greater transparency of Atlas strengths (and weaknesses) will help others understand Atlas' specific competitive advantages and potential contributions.

Example: Construct Data for Policy Stories. To improve communication about how decision makers can (and cannot) use Atlas data, the Atlas team can develop better explanations about how the data has contributed to decision-making in the past, including lessons learned about data limitations. The current impact assessment, while excellent for presenting what was done, provides little understanding of how data are actually used for decision making https://allencoralatlas.org/blog/impact-report-2021/. Policy and governance decision-making contexts are highly complex and it would be helpful to develop more detailed stories about how planners, policy makers, public managers, NGOs and local communities integrated Atlas data. We believe Atlas could better capture ridge-to-reef planning activities that are currently underway or complete, for example in Belize and the Philippines. We suggest that these stories should be user-oriented, written for and by audiences in the Global South, and highly conscious of the policy and decision-making complexities of the ridge-to-reef. Please see this example that is related to oceans, but not specific to ridge to reef: http://media.wix.com/ugd/c04ef4_7a0b6247736f4cc5b4d1b13efccb9a95.pdf

Atlas Use Case 2: Consider opportunities for expanded application for policy and governance

Policy challenge: Limited uptake of existing Atlas data and information by policy and decision makers for global conservation efforts.

Articulating the Use Case: To advance metric development. One option would be to create a global sample of 90%-complete-coverage-MPAs for global monitoring

Potential impact: An Atlas metric of global reef health may be used as a key input for global policy making, or for monitoring progress (or not) toward SDGs

Use case detail: Atlas data is currently being used in ways that help marine spatial planning, including the expansion and management of marine protected areas (MPA). Mostly, this seems to be related to providing accurate data on reef coverage and extent such that MPA boundaries may be revised, or to monitor reef health within MPA boundaries (as well as along coastlines). It is possible that Atlas could build on a stronger commitment to transparency of science communication to establish a global monitoring tool for shallow-depth reefs that aligns with the strengths of its data.

In discussions with ridge-to-reef experts, it became apparent the Atlas is primarily of value for mapping and monitoring shallow reefs. Additionally, Atlas data include all MPA boundaries globally. While we are not experts on coral reef biology or MPA mapping, we would encourage Atlas to consider whether it can identify a sample of MPAs that have characteristics that play to Atlas strengths. For example, Atlas could identify MPAs that are:

1) fully covered by Atlas data such that they are primarily shallow;
2) globally dispersed in some well recognized way (e.g. regionally);
3) comprise high, high resolution data over longer time periods.

This subset of MPA's could provide a representative global sample that Atlas could monitor – providing global and regional reef quality statistics for shallow reefs on a monthly basis, for example. Atlas could develop a communication tool (e.g., twitter or email blast) aimed at conservation scientists, policy makers, MPA authorities and others.

Similarly, we came across an ArcGIS clip tool that might be useful for metric development: https://pro.arcgis.com/en/pro-app/2.8/tool-reference/analysis/clip.htm. The clip tool can be used to select out the portion of the Atlas benthic map that is within the MPA boundaries and then create a new benthic map layer for areas within MPA boundaries. Because both MPA and Atlas data are in shapefiles, this process is relatively easy. This tool may also be useful for the representative global sample discussed above.

Atlas Use Case 3: Consider opportunities for expanded services for policy and governance

Policy challenge: Need for coral reef data for ongoing monitoring of local reefs and for management and governance of coastal ecosystems in countries/localities that have limited capacity to use data.

Articulating the Use Case: Using Atlas as an integrated data tool for informing decision making on the land that may impact the reef requires multiple different capacities: data analytics, science communication, local knowledge, data for governance and decision making, among others. Atlas would greatly increase the usability and usefulness of the data, particularly in the Global South, if it also considered developing extension services.

Potential impact: Opportunity to use data as a collaborative tool for governance and decision making. Improved management of coral reefs in Global South. Improved accessibility of Atlas data for countries with less training and resources in spatial data and data analytics.

Use case detail: One consequence of a purely open data for research approach to big data science, is the lack of co-aligned services for the uptake and meaningful use of the data. In discussions with experts, it is clear that most coral reef / ridge-to-reef planning and decision making is a highly complex activity, much of which takes place locally and involved multiple stakeholders, many of whom have conflicting interests. Systems of governance, concentration and distribution of political authority, cultural values, laws norms and practices, technical capacity, and local priorities all create a context in which the use and usability of data are particular to location. Given this, Atlas should consider that limitations of an 'open data' approach that is not accompanied by services and assistance to local actors in ways that increase access and ability to harness the data for decision-making.

We know that the Atlas team is involved with government actors in Belize and the Philippines, helping them access and use Atlas data. But we believe the role that Atlas plays is substantially a traditional 'open data' approach; it does not consider the broader range of services that may be critical for local uptake and eventual impact. One option for Atlas is to invest in a broader set of skills and services that would contribute training, capacity building, consultation, in-country liaisons. Such investments would deepen Atlas' impact, especially in severely under resourced localities.

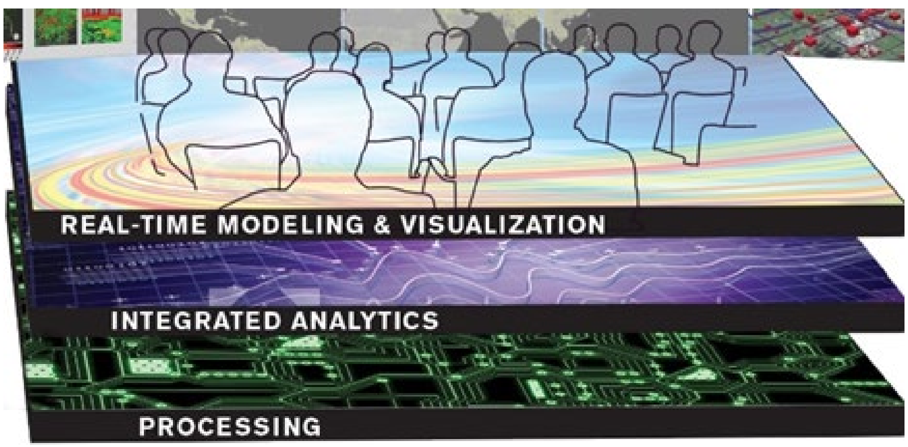
In our own recent discussions with the government of Colombia, we learned of a large reef recovery effort that includes mangrove forestation and coral out-planting. The government of Colombia has already conducted a mapping exercise, but the expressed interest in historical data for shallow reefs. The Colombian research community is strong and potentially a good potential partner for further co-developing a set of services that would assist management, monitoring and decision-making efforts. As we continue to interact with the Colombian government, we will explore ways in which Atlas data could be leveraged through existing partnerships in Colombia, as well as through the development of integrative local language engagement on:

1. integration of Atlas and other data (presented in the rest of this document);
2. training in the use of big data for reef monitoring;

3. science communication and governance workshops;
4. multi-stakeholder effort to explore the use of integrated ridge-to-reef data for decision making and governance related to continuity of ridge to reef and human to natural systems;

Although it is early, we believe the extended services / workforce development approach would be of high value. These services could be provided by a regional or local partner.

Example: Integrated decision-making platform. Atlas could implement a co-creation model for a **decision-support platform** that brings together diverse stakeholders in facilitated decision environments to explore complex problems, share, prioritize, analyze, and visualize data, and evaluate solutions from available perspectives. The decision support platform will have three tiers (Figure 1). The first tier comprises the foundation of ridge-to-reef data open and accessible to all stakeholders. These data come from multiple sources as is already evident in the Atlas system, but also highlighted in the use cases that follow. The second tier contributes data analytic and visualization components produced through the Atlas interface. The platform may require new data manipulation tools or flexibilities to respond to stakeholder queries. The third tier – facilitated decision-making for governance and policy – brings together relevant local stakeholders. This top layer the decision support platform enables greater understanding of complex problems while providing decision makers, influencers, and researchers the opportunity to explore the trade-offs of decision alternatives.



The platform's evidence-based approach to decision making could be used to strengthen local capabilities in gathering data, link existing local data to Atlas, statistical analysis and modeling, and communicating ridge-to-reef complexities across different stakeholders. It would also require Atlas to invest in governance expertise and other skills. Ultimately, the decision support platform could take a deliberately inclusive approach to engaging stakeholders in transparent and participative decision-making for the purposes of ridge-to-reef governance.

Atlas Use Case 4: Extending Atlas reef data to the ridge for policy and decision making: the 'low hanging fruit'

Policy challenge: Need for data that captures the continuity of land use and coral reef data for management and governance of coastal reef ecosystems

Articulating the Use Case: Atlas is interested in affecting decisions on the land that may affect coral reef health. As a first step, it could consider more seamless integration of Atlas data with other datasets that capture changes in natural systems on land. Many of the ridge focused datasets capture land use and land quality changes (e.g. deforestation, agricultural use, fires, etc.) facilitating research and potentially increasing local understanding of the integrated relationships between shore and marine ecosystems.

Potential impact: Greater integration of ridge-to-reef data systems holds promise for improved management of coral reef health, particularly in Global South.

Use case detail: Atlas is particularly interested in understanding what potential opportunities may exist to integrate a Ridge to Reef data component. As part of this project, the CSTEPS research team conducted a broad scan of the literature and other ridge data systems that could potentially be matched to Atlas reef data. Some of these are more obvious and available than others. In discussing the more obvious examples with Atlas, it was apparent that some of them are currently underway. In this section we cover the 'low hanging fruit' expansion ideas that include existing data that are not yet connected either through direct integration with Atlas data or through APIs.

In our discussions and reviews, it is clear that the management and governance of the ridge may be an important means of reducing reef and related biological diversity loss. For example, deforestation and wildfires contribute to erosion and runoff on the ridge which can result in higher turbidity in the reef. And yet, controlling deforestation is a highly complex policy issue, especially in lower income economies where forest products carry high value and enforcement is limited. Additionally, it appears that some global datasets are not continually updated. For example, it is difficult to identify a regularly updated agricultural use data base, and some dataset are of lower quality (based on interviews). Nevertheless, there are substantial potential opportunities for linkage to ridge datasets. Examples include:

a. Forest Cover and Destruction. Data focused on land cover, forest lost, and forest cover could be combined with Atlas data to show how deforestation can impact reefs (bleaching, turbidity, etc.). Additionally, visualizations could be used to communicate varying scenarios (across deforestation, reforestation, gradient, etc.)

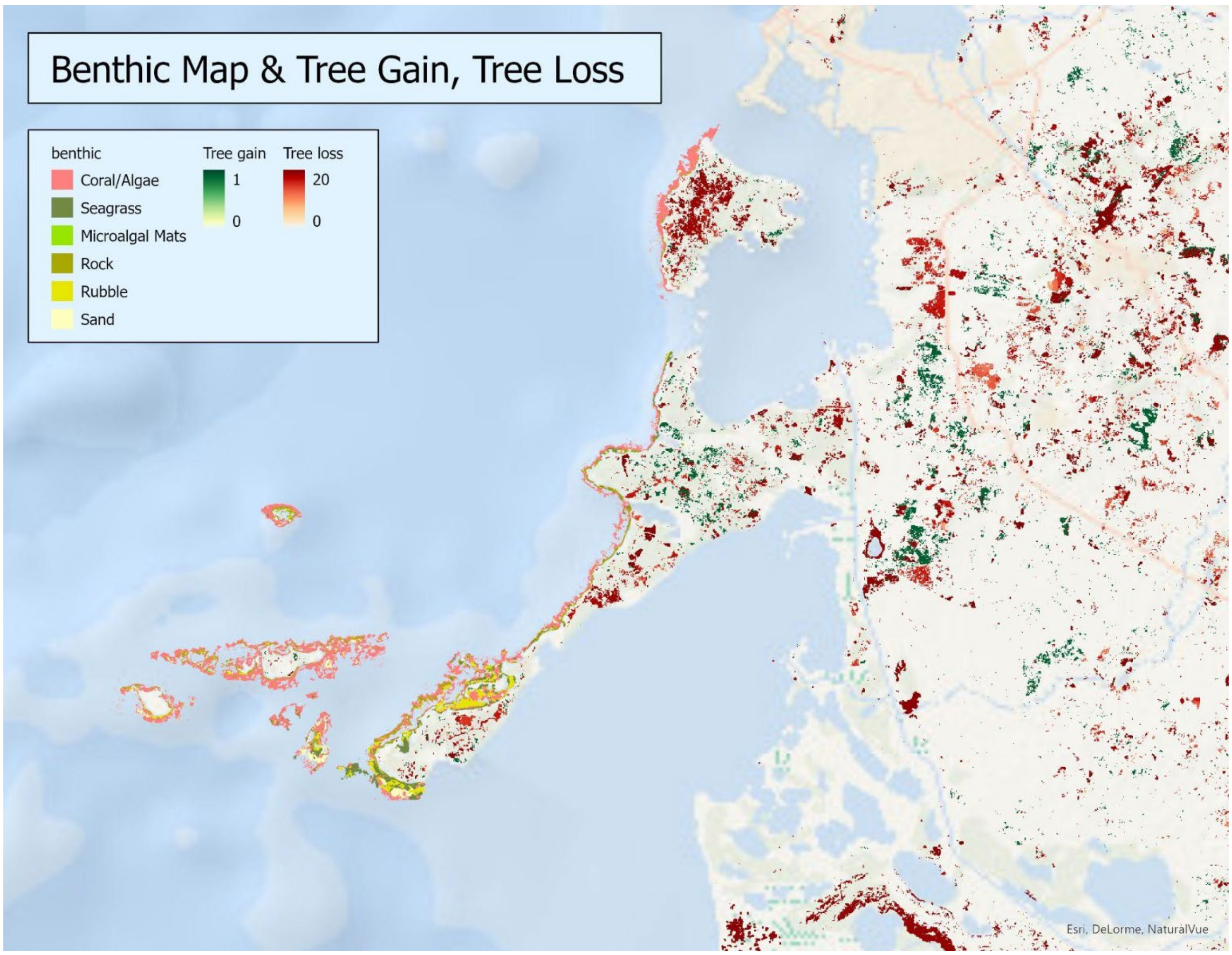
   "Deforestation can cause high amounts of soil erosion. With rainfall the loose soil finds its way into coastal waters through waterways. The muddy freshwater smothers the coral, blocking light and damaging coral tissue, which can lead to bleaching and deterioration of the reef" (https://theconversation.com/manage-the-land-to-protect-the-reefs-15076#:~:text=Deforestation%20can%20cause%20high%20amounts,the%20reef%20and%20its%20ecosystem)

World Bank Deforestation Data. Global Maps of 21st-Century Forest Cover Change by University of Maryland, https://storage.googleapis.com/earthenginepartners-hansen/GFC-2020-v1.8/download.html

Forest cover loss layer: Forest loss during the period 2000–2020, defined as a stand-replacement disturbance, or a change from a forest to non-forest state. Encoded as either 0 (no loss) or else a value in the range 1–20, representing loss detected primarily in the year 2001–2020, respectively.

Forest cover gain layer: Forest gain during the period 2000–2012, defined as the inverse of loss, or a non-forest to forest change entirely within the study period. Encoded as either 1 (gain) or 0 (no gain).

Figure 1. Cartagena Colombia Region, Integrating Tree Gain and Loss with Atlas Data



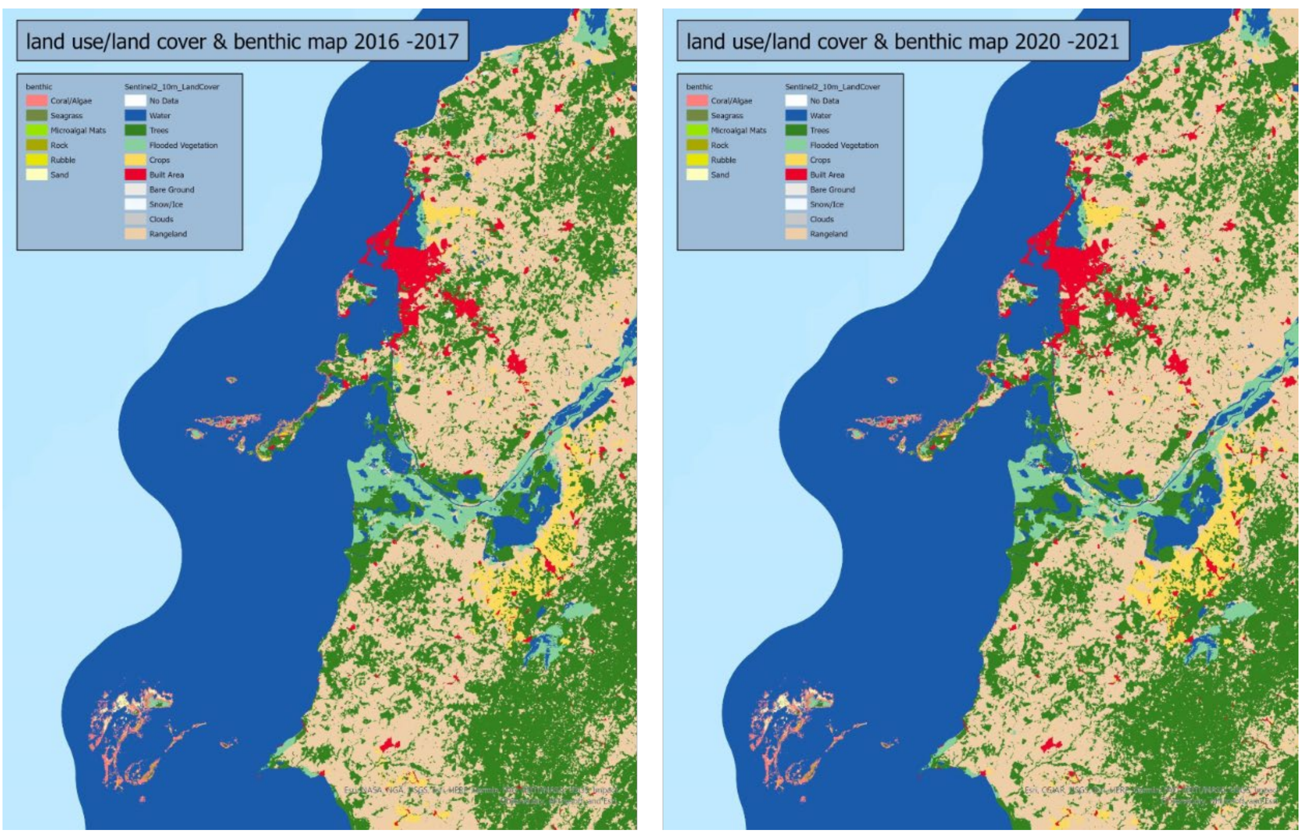
b. Land cover data. ESRI land cover data could be combined with Atlas data to demonstrate land use patterns near coral reef areas.

> Different types of land use may correlate to various negative impacts to the reef. For example, runoff from cleared or urbanized land may contribute to increased turbidity from eroded sediment, or toxicity from urban derived pollutants. Runoff from agricultural lands is known to cause eutrophication and subsequent coral bleaching and die-off.

Sentinel-2 10m Land Use/Land Cover Timeseries. https://www.arcgis.com/home/item.html?id=d3da5dd386d140cf93fc9ecbf8da5e31

- Generated from Impact Observatory's deep learning AI land classification model, Source: Produced by Impact Observatory, Microsoft, and ESRI
- Resolution: 10m, resolution compatible with Atlas benthic map
- Years: 2017, 2018, 2019, 2020, 2021

Figure 2. LUCC, ESRI Data, Cartagena, Colombia

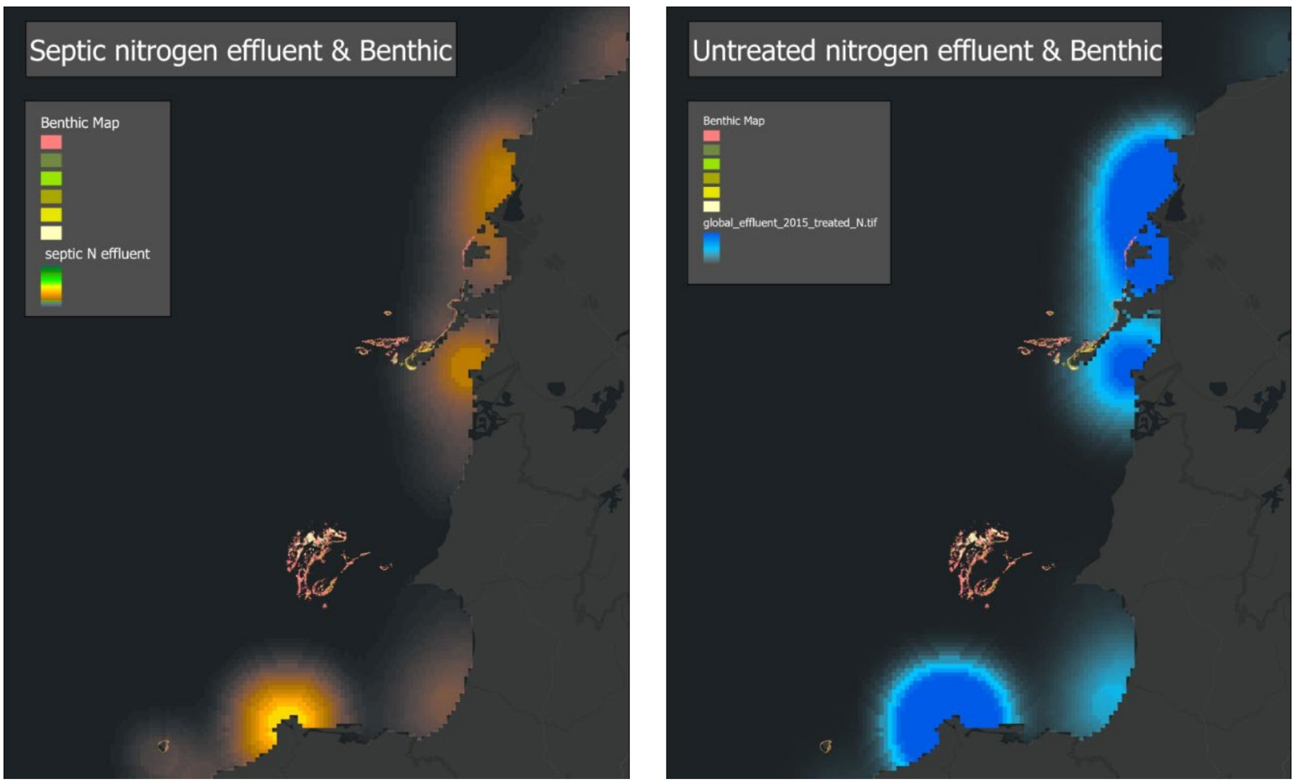


c. Coastal wastewater effluent data. Data on coastal wastewater effluent could be combined with Atlas data.

For example, global inputs and impacts from of human sewage in coastal ecosystems could be mapped for areas near coral reefs (https://pubmed.ncbi.nlm.nih.gov/34758036/). Untreated sewage may be harmful to reef ecosystems due to eutrophicication from increased nutrient inputs (nitrogen and phosphorus), chemicals and pathogens.

- A human wastewater map that entered coastal waters, enables quantification of the pathogens and nitrogen from human sewage for ~135,000 watersheds
- Resolution: Nitrogen effluent map resolution is lower than Atlas
- Model Year: 2015

Figure 3. Septic and untreated nitrogen effluent matched with Atlas data, Cartagena, Colombia



d. Extreme event and disaster data. See: https://www.nature.com/articles/s41597-021-00846-6 [https://sentinel.esa.int/web/sentinel/thematic-areas/emergency-management; https://www.gdacs.org/, resource watch]

e. Global Fire Weather Database on Global Forest Watch https://data.giss.nasa.gov/impacts/gfwed/

- Based on the Fire Weather Index (FWI) System, the Global Fire Weather Database (GFWED) integrates different weather factors influencing the likelihood of a vegetation fire starting and spreading

Figure 4. Global Fire Weather data from Global Forest Watch, May 2, 2022

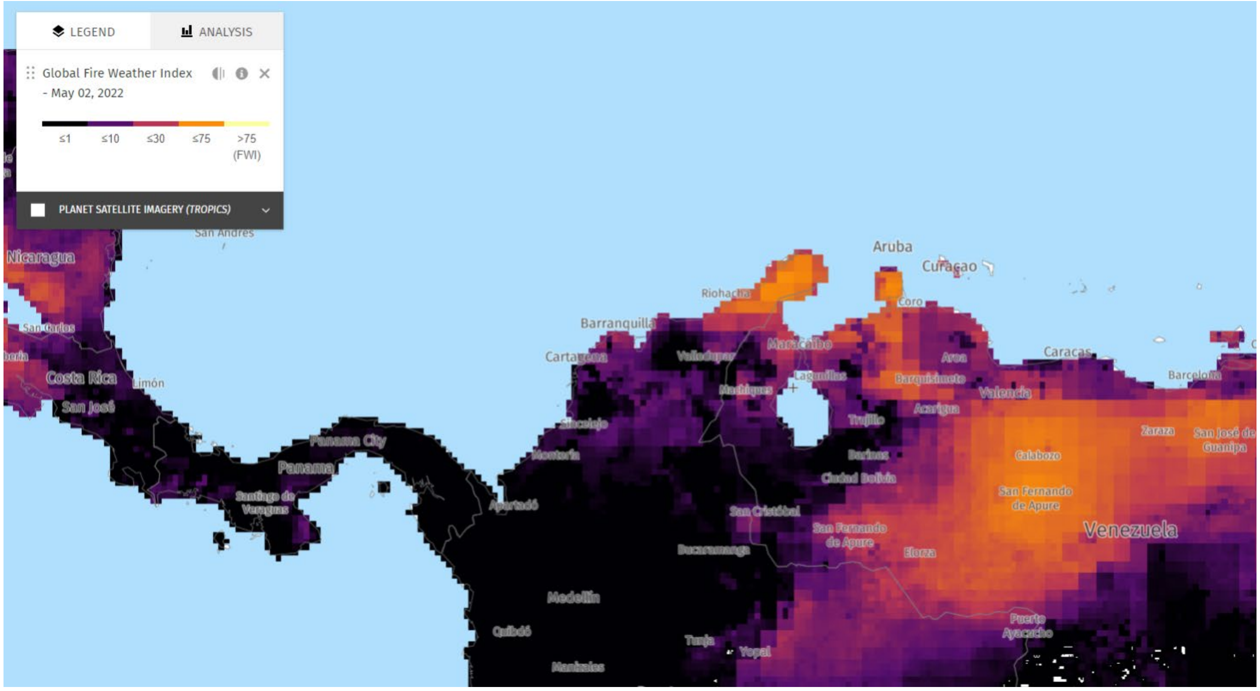
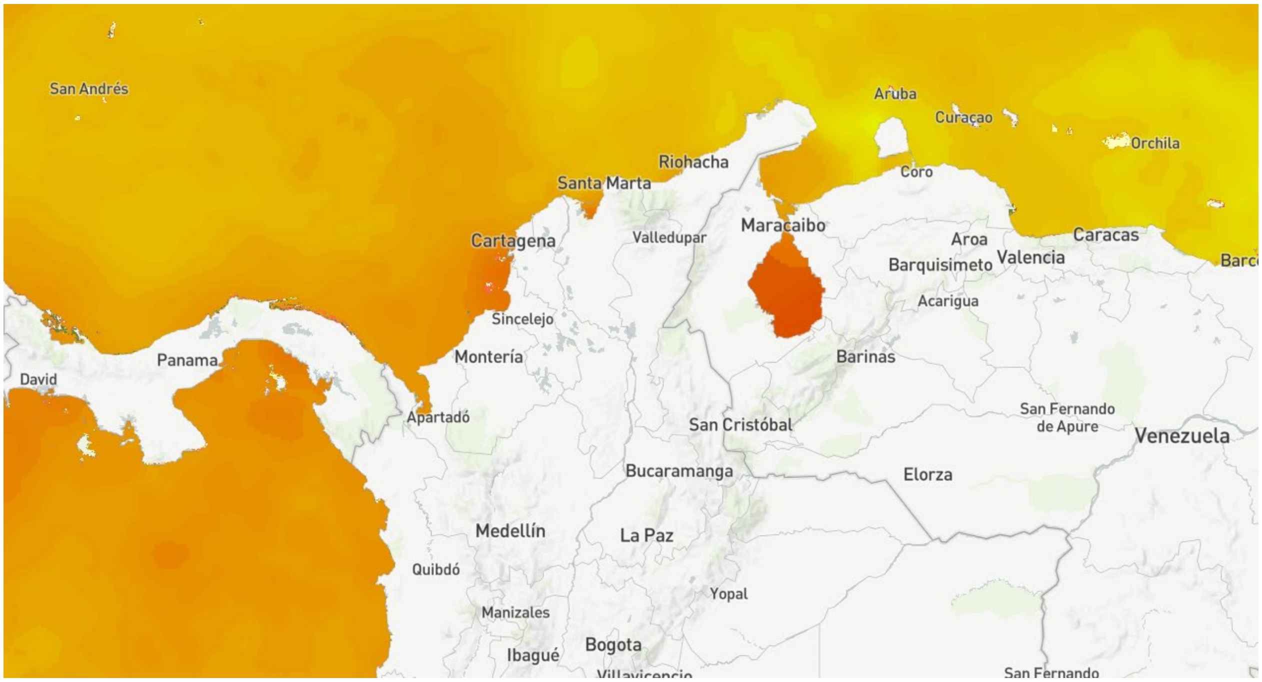


Figure 5. Sea Surface Temperature, Atlas, May 2, 2022



Atlas Use Case 5: Extending Atlas reef data to socioeconomic data for informing ridge to reef policy and decision making

Policy challenge: Need for data that captures the continuity of human systems and coral reef data for management and governance of coastal reef ecosystems.

Articulating the Use Case: Administrative boundaries provide an entrée into linking with data from the World Health Organization (WHO), data regarding trade, data focus on tourism, and other human-centric data that also changes over time. Connection with readily available and robust socio-economic systems data - population, income, urbanization, economic and trade, health and disease, education – first requires the inclusion of administrative boundaries. Administrative boundaries are also important if Atlas would like to add, for example, relevant local or regional laws and regulations, network governance agreements, or responsible parties.

Potential impact: Improved governance and management of the interface between the human systems on the land and the coral reefs, particularly in the Global South

Use case detail: Atlas should consider that merging human systems data is perhaps more important than merging ridge-to-reef natural systems data. The ridge up from most reefs is inhabited by a wide variety of social systems that impact coral health. Because policy decisions are tied to jurisdictions, histories, cultures and multiple sources of authority, Atlas would be more useful for policy, management and governance if it also included administrative boundaries. In that way, natural systems impacts (e.g. runoff, fishing, etc.) are more easily attributed to certain locales and policy actors.

We believe that if Atlas would like to better capture the ridge, it should expand its approach to better identify the human context. As one example, Dr. Stacy Jupiter indicated that local populations are much more interested in how flooding might enable water-borne diseases and disease vectors that affect human health than how flooding might affect reef health. While only one example, it points to the indirect social complexities that 'filter' or 'exacerbate' ridge effects on the reef.

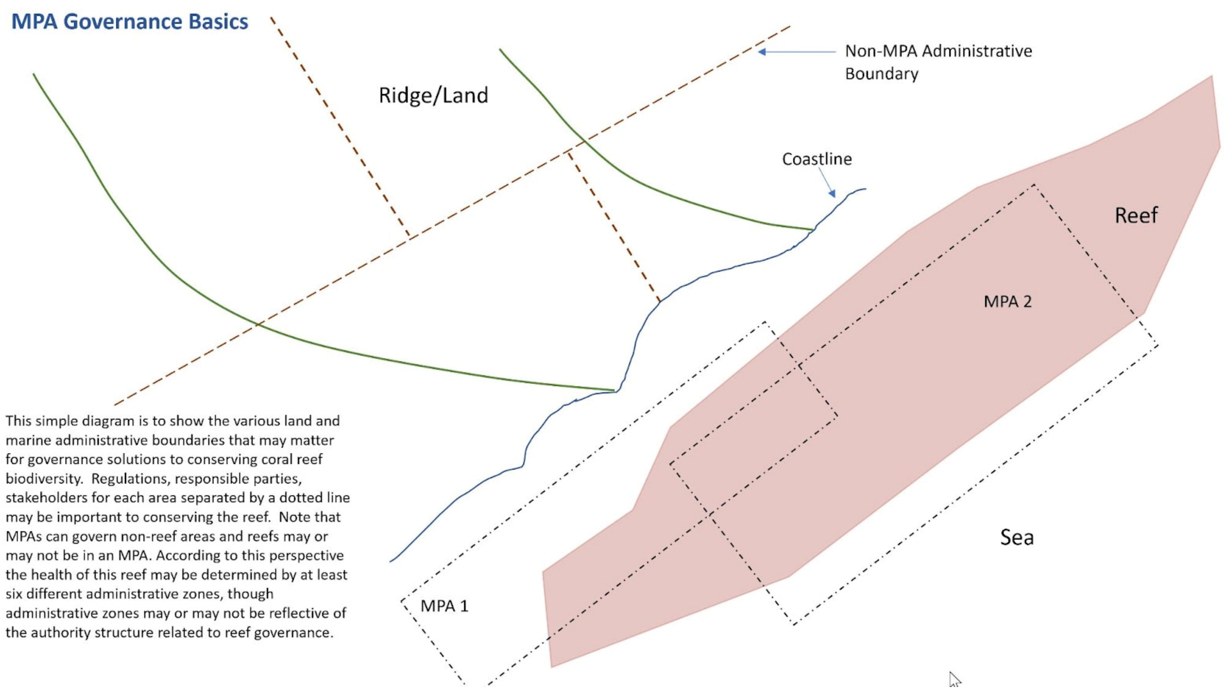
Another important implication of this concerns the tradeoffs that decision makers consider when setting rules and regulations on land. In many places, human needs, regardless of whether the impacts on reefs is direct or indirect, are often prioritized. This is understandable, particularly when resources are limited. But it is not reasonable to expect that decisions to conserve reef health will ever be made in isolation from decisions affecting human systems on the land. From interviews in the Virgin Islands, we learned that this process of connecting to and integrating the interests of organizations and groups on the ridge is time consuming and costly, but also critical for exposing vested interest and critical tradeoffs. Atlas data could benefit these kinds of activities through the open and transparent inclusion of socioeconomic data in its system.

Merging/linking of social systems data is one possible extension of Atlas that would include two interrelated activities:

1. Integrate highly detailed administrative boundary data into the Atlas database. [https://datacatalog.worldbank.org/search/dataset/0038272/World-Bank-Official-Boundaries] See simplified graphic with administrative boundaries in Figure 6.
2. Enable the linkage of Atlas data to human data – socio-economic data, human health and disease data, trade data, etc. Much of this data is collected by the United Nations, but it is also possible to collect data at the national or even local levels to more fully enhance the human systems perspective. Please see this for overview: https://www.brookings.edu/research/using-big-data-and-artificial-intelligence-to-accelerate-global-development/ [Publicly available national level: https://www.census.gov/programs-surveys/international-programs/about/idb.html; https://globalepidemics.org/key-metrics-for-covid-suppression/; https://guides.libraries.emory.edu/c.php?g=944707&p=6810116, Subnational microdata sometimes available by subscription; other subnational data could include: https://sedac.ciesin.columbia.edu/data/set/nagdc-population-landscape-climate-estimates-v4; https://sedac.ciesin.columbia.edu/data/set/ssp-1-8th-urban-land-extent-projection-base-year-ssp-2000-2100]

The integration of social systems data will begin an extension of Atlas to recognize the primary component of policy and governance on the land: humans and human societies. We do not expect that his effort would be excessively difficult. Most of these data are available as noted above. Our recommendation is for both policy and research reasons. For policy and governance, trade-offs will become more explicit, and local and regional actors can observe the actual and potential integrated impacts of land use on human and reef systems. For research, computational social scientist will be more able to connect to the critical reef conservation topics.

Figure 6: Distinctive Administrative Zones for Ridge to Reef Governance of Marine Protected Areas



Atlas Use Case 6: Extending Atlas reef data to the ridge for policy and decision making: 'stretch' use cases

Policy challenge: Need for data that captures the continuity of built human systems and infrastructure to help understand critical contributors to reef health such as runoff, sewage and other human footprint effects.

Articulating the Use Case: The infrastructure 'stretch' use case goes one step further than matching Atlas with World Bank urbanization data. Here we suggest using new tools and datasets that capture the build infrastructure (buildings, sewer systems, roadways, etc.) that exists at the coastal interface and upland.

Potential impact: Adding infrastructure data to Atlas potentially fills a knowledge gap between the human context and coastal/marine/reef impacts. Planners can identify, for example how roadways and building systems matter for flooding and effluent during storms that simultaneously impact human and reef health. Linking human systems data may help decision makers prioritize infrastructure investments that simultaneously address multiple outcomes, thereby minimizing decision trade-offs.

Use case detail: Recognizing that Atlas is making ongoing decisions about investments that increase the value and impact of the data, we also identified some potential areas of expansion that may be more difficult or costly to undertake. In all cases these ideas are deemed to be feasible and would result in the integration of new data sources and the development of new tools to capture linkages between human and natural systems.

The built infrastructure is a major component of the ridge area. Infrastructure footprint and use data can generate information about the proximity of human settlements to the reef, potential for runoff, level of economic development including sewer infrastructure, and many other important elements of human society.

Examples of open source infrastructure data include:

a. Microsoft building footprints https://www.microsoft.com/en-us/maps/building-footprints
b. Open street maps https://www.openstreetmap.org
c. Open address https://openaddresses.io/

These datasets can also be used in conjunction with urbanization data available from the World Bank [https://www.arcgis.com/home/item.html?id=d3da5dd386d140cf93fc9ecbf8da5e31]

We believe that the built infrastructure data could be merged with existing data on turbidity and nitrogen effluent to provide better assessments of the linkage between social systems and near shore reef impacts. For example, building footprints that are larger and closer to the reef may entail more extensive sewage treatment systems related to tourism (hotels, etc.). Small buildings (and very small buildings) on steep terrain, could indicate substantial opportunity for erosion and potentially raw sewage overflow during flooding events. These kinds of linkages would need to be done carefully with substantial ground-truth validation. Additionally, infrastructure data may be helpful in ascertaining or explaining urbanization effects on human health and disease. We believe, the potential for linking infrastructure data for meaningful understanding of urbanization, rural development, and reef health is high.

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APPENDIX 1: PROJECT ORIGINATION AND METHODS

Project Design

In fall 2021, the Center for Science, Technology and Environmental Policy Studies (CSTEPS) entered into a memorandum of understanding with the Allen Coral Atlas to identify potential use cases and strategies for integration of Atlas data and metrics into global, regional and national policy and decision-making contexts. The specific topical areas included were not specified, but they could include potential future monitoring and modeling applications related to land/sea interfaces.

The MOU set out to several tasks for completion by the end of spring semester 2022. These include:

1. Consult with Atlas staff to review information on prior use cases and prioritize potential future use cases. Develop a framework for selection of use cases.
2. Conduct literature review on current policy landscape. Review could include, but is not limited to: identify data and metrics currently used in policy and planning decisions, identify gaps in knowledge or data needs that could improve decision making, identifying emerging areas of interest for policy makers, NGOs, etc.
3. Interview initial stakeholders and partners (identified by Atlas team and through CSTEPS review) to determine current and future use cases, data needs, and better understand policy decision processes. Conduct follow up interviews as needed to fill in information gaps for selected use cases.
4. Outreach to individuals with relevant expertise to form policy advisory committee for future consultation and partnership.
5. Develop final report on findings, including use case descriptions as well as recommendations for partnerships and future directions for Allen Coral Atlas. Report due end of spring term 2022.
6. Provide progress updates on a monthly basis, and/or join occasional Allen Coral Atlas team meetings as appropriate.

Support from Atlas was sufficient to hire a graduate assistant, but it was soon evident that the project would require substantial investment of faculty time at CSTEPS. The CSTEPS project team met at least weekly, often we met more often. Since the beginning of the project the CSTEPS team has met with one or two members of the Atlas team to coordinate, communicate and reflect on findings. We have found that the interaction has become more effective and mutually valuable over the course of the project.

This report provides a general response to Atlas' initial desire for use cases, but it goes well beyond the anticipated list of activities and contributions. Our intention is to provide a robust interdisciplinary approach understanding the potential gaps and future responsibilities related to Atlas, a we understand them.

Methods

This exploratory project builds on CSTEPS experience in global policy and governance for big data research, much of which examines the access and use of biological and genomic data for international research and capacity building. It also builds on Atlas' engagement with the research community, current projects and prior use case experience, and work by its prior partner and funder Vulcan. A short initial meeting with the Vulcan partner in charge of government and policy provided some guidance in a half-hour hand-off discussion but no introductions to government or policy actors at any level. As a result, CSTEPS relied entirely on Atlas connections and its own networks.

CSTEPS undertook multiple avenues for understanding Atlas data, the Atlas website, big data coral reef research, and the marine policy and governance context. In particular, we focused on understanding potential opportunities for engaging Atlas in ridge-to-reef governance and policy.

Our activities included:

1. Literature review examining policy and governance related to coral reefs. Much of this literature concerns marine planning areas (MPA) and the governance factors that lead to MPA effectiveness. Some of the literature examined policy and governance issues surrounding ridge-to-reef. Finally, we also examined background grey literature on how big data use cases are developed and presented in other fields.
2. Interviews of a few scientists and government actors who are involved in ridge-to-reef projects, or responsible for reef conservation and planning.
3. Attendance and participation in seminars presenting big data approaches to understanding ridge-to-reef impacts or focused on the complex social and governance dimensions related to reef conservation.
4. CSTEPS hired an additional GRA to help us understand the quality and capacity of Atlas data, as well as potential other data sources that could be useful next steps for Atlas.
5. Development of a use case framework to guide identification of specific opportunities and gaps in Atlas, with the intention of informing better access and use of the data.