Teaching Notes: Sustainably managing a Hawaiian nearshore marine resource

"*Mālama i ke kai, a mālama ke kai iā ʻoe*"
(Care for the ocean, and the ocean will care for you)

Author Information: Chelsie W. W. Counsell, Hawaiʻi Institute of Marine Biology, chelsiew12@gmail.com, @CWCounsell

Author's Note: Please contact me if you use this case study to let me know the context in which it was applied & to provide feedback on the materials.

Summary: Managing natural resources in a fashion that does not negatively impact the resource for future generations, that is supporting sustainable resource use, is an increasingly common goal for resource managers. In the state of Hawaiʻi, a management goal has been set to sustainably manage 30% of nearshore marine resources by 2030. In this case study, students will (1) be introduced to needs of various stakeholders, (2) integrate multiple data streams to characterize a nearshore reef fishery, (3) describe feedbacks between the relevant social and environmental systems, (4) will propose a management plan, and (5) will peer-review the feasibility of policy proposals. While students will be encouraged to consider the full nearshore marine ecosystem, this case study is focused on *Acanthurus triostegus*, a small surgeonfish commonly referred to as the convict tang by visitors to the islands or as manini by people more familiar with local culture. This case study was designed for an upper level undergraduate course with an emphasis in ecology and/or environmental policy.

Estimated Time Frame:
This case study was designed for upper level, science major undergraduates. Completing all components should take about three 60 minutes class periods combined with some out of the classroom readings and project completion.

Socio-Environmental Synthesis Learning Goals:

- Understand the structure & behavior of socio-environmental systems (Modules 1, 2, & 3)
- Find, analyze, & synthesize existing data, ideas, or methods (Module 2)
- Consider the importance of scale & context in addressing socio-environmental problems

(Modules 2 & 3)

Learning Objectives:

Module 1 – Introduction to Ecosystem & Stakeholders

a. The students will be able to identify the environmental and social components of a nearshore fishery system.

b. The students will be able to identify interactions and feedbacks in the socio-environmental system of a nearshore fishery.

Module 2 – Integrating Multiple Data Streams

a. The students will be able to identify desired data and potential data sources for ecological and social data.

b. The students will be able to compare spatial patterns across data from multiple sources.

c. The students will be able to compare the context (e.g., variation in these data across space, time, and conditions) of the ecological and social processes.

d. The students will be able to identify missing data and discuss ways additional desirable data streams could be obtained.

e. The students will be able to explain the relative importance of feedbacks between social and environmental systems.

Module 3 – Adaptive Management Plan

a. The students will be able to propose an adaptive management plan.

a1. The students will be able to identify methods for monitoring the system that effectively measure management outcomes and include stakeholder assessments.

a2. The students will be able to produce a management plan intentionally designed to be able to respond to variation in the socio-environmental system.

b. The students will be able to evaluate the feasibility of a management policy proposal.

Classroom Management:

Module 1 -- *Introduction to Ecosystem & Stakeholders* (60 minutes)

Pre-class readings:

Tissot BN (2005) Integral marine ecology: community-based fishery management in Hawai‘i. World Futures 61: 79-95.

This article is about yellow tang and the aquarium fishery in west Hawai‘i. It highlights fishery, cultural, and ecological perspectives relative to a specific fishery management challenge (13 pages of text).

Jokiel PL, KS Rodgers, WJ Walsh, DA Polhemus, TA Wilhelm (2011) Marine resource management in the Hawaiian Archipelago: the traditional Hawaiian system in relation to the western approach. Journal of Marine Biology. doi: 10.1155/2011/151682.

This article is a great introduction or refresher for traditional reef management and recent reef management strategies in Hawai‘i. In particular, see table 1 for a succinct comparison of traditional and western management systems, and section 5 for a discussion of ways the two management styles can be synthesized (13 pages of text).

Class agenda:
(First 20 minutes for introduction & discussion)
Use the introduction on the student handout to begin the in class portion of the case study. Lead a class discussion utilizing the "think, pair, share" strategy for each of the following questions:

What does "sustainably manage" actually mean? How do we know if we're successfully sustainably managing a resource? What strategies might we use to design policies that would accomplish sustainable management? What factors should be used to determine which 30% of resources should be prioritized? (Can also work through these questions with the more specific question of what does it mean to sustainably manage a fishery?)

Learning objective 1a. The students will be able to identify the environmental and social components of a nearshore fishery system.

Activity 1a (25 min): The students will become familiar with the environmental and social components of the system by working in groups of two to construct a concept map of nearshore fishery system dynamics for manini along the windward coastline of O‘ahu. Concept maps need to include at least four social and four ecological elements (15 min). Use a word cloud with the key elements identified by all groups to start a course discussion of the system [Are all stakeholders identified? All ecological components?] (10 min).

Learning objective 1b. The students will be able to identify interactions and feedbacks in the socio-environmental system of a nearshore fishery.

Activity 1b (15 min): The students will add directionally explicit connections between elements on their concept maps (5 min). Have teams pair with another team to explain their connections (10 min).

Optional assessment: Student pairs write up a 1-page memo to explain the interactions and feedbacks presented in their concept map.

Module 2 – *Integrating Multiple Data Streams* (60 minutes)

Students will integrate information across multiple data streams to characterize a reef fish sustenance fishery.

Pre-class readings:

McCoy KS, ID Williams, AM Friedlander, H Ma, L Teneva, JN Kittinger (2018) Estimating nearshore coral reef-associated fisheries production from the main Hawaiian Islands. PLoS ONE 13(4): e0195840. https://doi.org/10.1371/journal.pone.0195840.

This article analyzes patterns in non-commercial and commercial fisheries in Hawai‘i. One key take away is the importance of non-commercial fishing as part of the system dynamics in Hawaiian nearshore ecosystems (7 pages of text).

Williamson DH, DM Ceccarelli, RD Evans, GP Jones, GR Russ (2014) Habitat dynamics, marine reserve status, and the decline and recovery of coral reef fish communities. Ecology and Evolution 4(4): 337-354.

This article includes discussion of no take marine reserves, monitoring programs, climatic disturbances on coral reef communities, and state shifts. This article also provides a good starting point for discussing temporal and spatial scales of ecosystem processes (15 pages of text).

Class agenda:

(First 10 minutes for introduction to Module 2 & discussion)

Use the paragraph on the student handout to begin the in class portion of Module 2.

We are currently at a time when we can use information from the natural sciences to reveal the spatial and temporal dynamics of a fish from spawning through larval stages to juvenile and adult life stages. These data can be paired with information from fisheries and social sciences to reveal the spatial and temporal dynamics of the capture and sharing of food resources. When considered in the context of the socio-environmental system in which the fishery occurs, this suite of data enables a holistic understanding of the system to guide effective management strategies. In this part of the case study, you will integrate information across multiple data streams to characterize a reef fish sustenance fishery (focused on manini along the windward coast of O'ahu). Discuss with a neighbor what types of data would you want to characterize the dynamics of, and ultimately to suggest management strategies for this socio-environmental system.

Have students start class by discussing with a neighbor what types of data they would like to have to characterize the dynamics of, and ultimately to suggest management strategies for this socio-environmental system.

Examples of data types to guide student discussions as needed:

- Ecological data, e.g., patterns of settlement, recruitment, survival, growth, reproduction, etc. These types of data of often obtained through field surveys to observe population dynamics and experimental work to more clearly define population regulation dynamics. Survey and experimental work can also be used to identify key habitat types (depth, benthic cover, etc.) for the species.
- Genetic data, e.g., relative genetic similarity across populations, kinship analyses, etc. These types of data confirm the pathways and the extent of pathways of larval dispersal within regions over years. Genetic data can show patterns of connectivity as well as self-recruitment. These data are typically collected through tissue samples, e.g., fin clips, collected with lethal or non-lethal methods.
- Oceanographic data, e.g., biophysical models incorporating wave energy, wind patterns, underlying currents, tides, etc. These data can be use to explore the importance of various biophysical factors for connectivity as well as to predict and generalize patterns of connectivity.

- Fisheries data, e.g., patterns of fishing effort and landings, gear types, community-based importance of fishing, dissemination of catch through social networks, and fishing access points, etc. These data can be used to characterize fishing pressure and to depict the importance of fishing for the community.
- Land-based pollutants, e.g., nutrient runoff & sedimentation loads, prevalence of impervious surfaces, land use history, flooding patterns, etc. These data can be used to characterize stress inputs into the system.
- Historical cultural value, e.g., references to this fish in songs, chants, or poems. These data can be used to depict the importance of this resource throughout Hawaiian history.
- Tourism patterns, e.g., number of tourists, tourism activities of interest, any data connecting tourism to manini specifically. These data can be used to connect tourism to manini and evaluate tourists as potential stakeholders.
- Existing management strategies, e.g., general fishing rules, protected areas, specific rules for manini, enforcement strategies and related resources, etc. These data provide insight to the current strategies and priorities of local management efforts.
- Conservation patterns, e.g., number of community based clean up efforts, community's general appreciation for nearshore resources, presence and size of community activist groups, etc. These data can be used to evaluate the role of conservationists as stakeholders and the general support from the community for conserving near shore resources.

Learning objective 2a. The students will be able to identify desired data and potential data sources for ecological and social data.

Activity 2a (20 min): Students work in groups to find, obtain, and review relevant data. These data may include a variety of formats, e.g., traditional datasets, pre-formed graphs and maps, lists of information, key pieces of information, etc. Have each group keep a clear record of each finding that includes the general type of data, the source location / data provider, and key takeaways from that dataset, e.g., important trends or patterns observed.

Potential data sources are listed within the background information section of the teaching notes.

Learning objective 2b. The students will be able to compare spatial patterns across data from multiple sources.

Activity 2b (30 min): Remaining in the same groups as for Activity 2a, have students create storyboards of how they expect the datasets they found may be connected. Have them sketch out the analyses / patterns relative to these data that would help them characterize the socio-environmental system. Encourage them to predict the relationships they expect to find in these data (10 min).

Goals for working with these data may include identifying and defining key habitat (ecologically and socially), identifying key stressors and potential management strategies,

depicting connectivity along the coastline, etc. Analyses may include linear regressions and multiple regressions (these could be spatially explicit), PCAs, etc.

Remaining in the same groups, have the students select two data sources that are of most interest to them. Using these two datasets, what information do they have about the system? Add in one more dataset, and now characterize the system. Repeat this step until each group is considering 4-6 datasets.

Have each group pair with another group and share their data-based characterization of the system. Discuss the similarities and differences in the two groups system characterizations. Did they choose the same datasets? What motivated their decisions about which data streams to use? Did these decisions bias your characterization of the system? (10 min)

With these sets of two groups working together as a larger team, have the students again characterize the system. (10 min)

Optional Modification: Depending on the background of students and the overall course goals this activity can vary from having the students find data and discuss potential analyses to having them develop and complete their own analyses.

Learning objective 2c. The students will be able to compare the context (e.g., variation in these data across space, time, and conditions) of the ecological and social processes.

Activity 2c (10 min): Have students stay in the same groups as at the end of Activity 2b (if these groups are too large or rowdy, could have students split back into original, smaller groups). Working with the questions on the student handout have the groups discuss the spatial and temporal extent of each dataset. How do these vary across the datasets? How might this impact the ability to integrate these data streams? Is there a feasible option to make the context of the data streams more consistent?

Learning objective 2d. The students will be able to identify missing data and discuss ways additional desirable data streams could be obtained.

Activity 2d (10 min): Splitting back into groups of two, identify at 1-3 social and 1-3 environmental datasets that they were not able to find and that would provide useful insights into the system (5 minutes to create a data wish list).

Have the students create a plan for how they could feasibly access and/or collect these data (5 min).

Optional assessments (for activities 2a – 2d): Possible items to collect include tables of data sources obtained, storyboards of data analysis plans, final characterization of the system after adding in various datasets and pairing with teams, and data wish list with plans for data collection. Another assessment option would be to have each team present their system characterizations with the class, including their responses to 2c & 2d in 5-10 minute talks.

Learning objective 2e. The students will be able to explain the relative importance of feedbacks between social and environmental systems.

Activity 2e (after class): The students will update their concept maps and prepare a 1-page memo explaining the cause, directionality, and strength of all linkages on their concept maps.

Module 3 – *Adaptive Management Plan* (60 minutes)

Students will prepare a management plan, peer review management plans from other groups, and finalize their management plan with a focus on feasibility, intentional ability to adapt to changes in the system, and relevant monitoring efforts.

Pre-class readings:

Maui Coral Reef Recovery Team (2015) Ola nā Papa i Mālama ʻia: A practical plan for the technical and cultural restoration of Maui's coral reefs. Version 2.0. Maui Nui Marine Resource Council, Kīhei, Maui. 116pp. https://www.mauireefs.org/

Example of a management plan proposal. This is a long document. Encourage students to skim the full document and be able to articulate at least five distinct take away points (83 pages of text).

Ke Kukulu Ahu: Aha Moku Advisory Committee Strategic Plan (2013) http://dlnr.hawaii.gov/ahamoku/files/2013/09/Ke-Kukl-Ahu-Strat-Plan-Template-DLNR.docx

This advisory plan from the Hawaiian Department of Land and Natural Resources includes a nice layout of a strategic plan with each act, function, description, resource tools, and implementation timeline for a few specific focus areas (12 pages of text).

Class agenda:

(Take a few minutes to introduce Module 3)

The paragraph on the student handout can be used to begin the in class portion of Module 3.

Often, policy makers do not have all the data they desire; yet they need to develop policy strategies. Effective management strategies are reasonable given the ecological parameters of the system, consider the values and needs of various stakeholders, have feasible enforcement strategies, include a plan to monitor key elements of the socio-environmental system, and are able to respond to changes in the socio-environmental system.

Learning objective 3a. The students will be able to propose an adaptive management plan with the goal of a sustainably using this reef fish.

a1. The students will be able to identify methods for monitoring the system that effectively measure management outcomes and stakeholder assessment.

a2. The students will be able to produce a management plan intentionally designed to be able to respond to variation in the socio-environmental system.

Activity 3a (20 min): Have the students form groups of 2-4 with different students than they were working with in Module 2. Encourage the students to outline the key elements they want to include in their proposed management plan (5 min). Develop these ideas and ensure they are incorporating the core components of an effective management plan. Prepare a memo to present your proposed management plan (15 min).

Assessment: Have students create a 1-page white memo depicting the details of the group's proposed adaptive management policy. This should include regulations, enforcement, a monitoring plan, a means of responding to shifting dynamics, and a measurement of success.

Learning objective 3b. The students will be able to evaluate the feasibility of policy proposals.

Activity 3b (30 min): Have student teams trade their policy plans with another group (groups should stay spatially separate for now). Have student groups peer-review the feasibility of another team's policy proposals. Students should add comments evaluating how feasible their peers' plan is given ecological parameters, stakeholder support, and enforcement capacity. They should also evaluate the ability of the proposed plan to recognize shifts in the system (effective monitoring), to be adjusted given shifts in the system, and to evaluate success of the management strategies. Students performing the peer-review should add their initials to the document their thoughtful participation in the peer-review process (20 min).

Have the students form merged groups with the group that they peer-reviewed. Taking five minutes to focus on each team's proposal, have the groups share their overall feedback and present a few specific recommendations to the other team (10 min total).

Assessment (10 min, groups will likely complete this task after class): Have the student groups modify their team's proposed management policy. Encourage them to make a clear plan for how they will complete their final proposal.

Student groups will hand in their original policy plan including feedback from their peers, and a final 1-3 page policy proposal, and a final systems dynamics concept map for assessment.

Introduction:

"*Mālama i ke kai, a mālama ke kai iā ʻoe*" (Care for the ocean, and the ocean will care for you)

Coral reef ecosystems are exceptionally valuable. Ecologically coral reefs have high species diversity; economically they support tourism, fisheries, and shoreline protective services; and culturally they have high value for the native Hawaiian and other island communities through community engagement in traditional fishing practices, as a source of extracted resources, and as a component of spiritual practices.

Yet, these ecosystems face many challenges including over fishing, sedimentation, nutrient input, direct harvest of coral, destructive fishing practices, warming water, increased frequency and intensity of bleaching events, increased frequency and intensity of storm events, and ocean acidification.

Within the Hawaiian Department of Land and Natural Resources is the Division of Aquatic Resources. From their website, "The mission of the Division of Aquatic Resources is to work with the people of Hawaiʻi to manage, conserve, and restore the state's unique aquatic resources and ecosystems for present and future generations." More specifically, as part of the

Aloha Challenge, https://dashboard.hawaii.gov/aloha-challenge, a goal has been set of sustainably managing 30% of nearshore resources by 2030.

For this case study, students will grapple with what it means to sustainably manage a resource. Students will (1) be introduced to needs of various stakeholders, (2) integrate multiple data streams to characterize a nearshore reef fishery, (3) describe feedbacks between the relevant social and environmental systems, (4) will propose a management plan, and (5) will peer-review the feasibility of policy proposals. While students will be encouraged to consider the full nearshore marine ecosystem of Hawai‘i, this case study is focused on *Acanthurus triostegus*, a small surgeonfish commonly referred to as the convict tang by visitors to the islands or as manini by people more familiar with local culture. Students will study the socio-environmental system of manini along the windward coast of O‘ahu to develop key skills that can be applied to various other socio-environmental systems.

Additional Background Information & Potential Data Sources:

I. Background information on the cultural / community value of fisheries in the Hawaiian Islands can be found in the following resources (the first two are suggested pre-class readings for Module 1):

- Tissot BN (2005) Integral marine ecology: community-based fishery management in Hawai‘i. World Futures 61: 79-95.

This article is about yellow tang and the aquarium fishery in west Hawai‘i. It highlights fishery, cultural, and ecological perspectives relative to a specific fishery management challenge (13 pages of text).

- Jokiel PL, KS Rodgers, WJ Walsh, DA Polhemus, TA Wilhelm (2011) Marine resource management in the Hawaiian Archipelago: the traditional Hawaiian system in relation to the western approach. Journal of Marine Biology. doi: 10.1155/2011/151682.

This article is a great introduction or refresher for traditional reef management and recent reef management strategies in Hawai‘i. In particular, see table 1 for a succinct comparison of traditional and western management systems, and section 5 for a discussion of ways the two management styles can be synthesized (13 pages of text).

- Delaney DG, LT Teneva, KA Stamoulis, JL Giddens, H Koike, T Ogawa, AM Friedlander, JN Kittinger (2017) Patterns in artisanal coral reef fisheries revealed through local monitoring efforts. PeerJ 5: e4089.

This article depicts spatial patterns in nearshore fisheries catch, effort, and catch rates. It evaluates the drivers of marine harvest and discusses issues of food security, cultural practice, and ecological value.

- https://www.fisheries.noaa.gov/science-blog/how-many-fish-are-being-caught-reefs-near-shores-hawaii

This blog post discusses fishing as a part of life, the importance of non-commercial fishing & challenges to monitoring non-commercial fishing efforts.

- http://www.ulukau.org/elib/cgi-bin/library?e=d-0maly1-000Sec--11en-50-20-frameset-book--1-010escapewin&a=d&d=D0&toc=0

This website has a history of fishing practices and marine fisheries for the Hawaiian Islands including a discussion of various methods for the Hawaiian governance and management of fisheries.

- http://castlefoundation.org/investments/marine/

This webpage section focused on marine resource conservation in Hawai‘i (and particularly the subsection on theory assumptions) prepared by the Harold K. Castle Foundation nicely articulates the importance of marine resources in Hawai‘i and some of the challenges faced.

II. Example strategies for fisheries management can be found in the following resources (suggested pre-class readings for Module 3):

- Maui Coral Reef Recovery Team (2015) Ola nā Papa i Mālama ‘ia: A practical plan for the technical and cultural restoration of Maui’s coral reefs. Version 2.0. Maui Nui Marine Resource Council, Kīhei, Maui. https://www.mauireefs.org/

Example of a management plan proposal. This is a long document. Encourage students to skim the full document and be able to articulate at least five distinct take away points (83 pages of text).

- Ke Kukulu Ahu: Aha Moku Advisory Committee Strategic Plan (2013) http://dlnr.hawaii.gov/ahamoku/files/2013/09/Ke-Kukl-Ahu-Strat-Plan-Template-DLNR.docx

This advisory plan from the Hawaiian Department of Land and Natural Resources includes a nice layout of a strategic plan with each act, function, description, resource tools, and implementation timeline for a few specific focus areas (12 pages of text).

III. Background information on adaptive management & monitoring to assess the success of management goals can be found in the following resources.

- Walters CJ (2007) Is adaptive management helping to solve fisheries problems? AMBIO 36(4): 304-307 https://doi.org/10.1579/0044-7447(2007)36[304:IAMHTS]2.0.CO;2
- Jones ML, GJA Hansen (2014) Making adaptive management work: lessons from the past and opportunities for the future. Taylor WW, Leonard N, Lynch A, eds. Future of Fisheries: Perspectives for the Next Generation of Professionals. American Fisheries Society, Bethesda MD.
- Hansen GJA, JW Gaeta, JF Hansen, SR Carpenter (2015) Learning to manage and managing to learn: sustaining freshwater recreational fisheries in a changing environment. Fisheries 40(2): 56-64.
- https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_013594.pdf

IV. Some information on the basic ecology of manini, *Acanthurus triostegus*, can be found in the following resources

- https://www.waikikiaquarium.org/experience/animal-guide/fishes/surgeonfishes/convict-tang/

- Frédérich B, O Colleye, G Lepoint, D Lecchini (2012) Mistmatch between shape changes and ecological shifts during the post-settlement growth of the surgeonfish, *Acanthurus triostegus*. Frontiers in Zoology 9:8. (in particular, see Fig. 6)
- Mohan M, CSG Pillai (1988) The biology of the convict surgeonfish *Acanthurus triostegus triostegus* (Linnaeus) from Minicoy Atoll, Lakshadweep. J. mar. boil. Ass. India 30: 182-191.
- Otwoma LM, V Diemel, H Reuter, M Kochzius, A Meyer (2018) Genetic population structure of the convict surgeonfish *Acanthurus triostegus*: a phylogeographic reassessment across its range. Journal of Fish Biology 93(4). https://doi.org/10.1111/jfb.13686
- Randall JE (1961) A contribution to the biology of the convict surgeonfish of the Hawaiian Islands, *Acanthurus triostegus sandoicensis*. Pacific Science XV.

V. This guide presents sustainability initiatives and potential measures in Hawai'i from the tourism / hotel perspective. A fairly long document that the students may benefit from skimming and finding at least five distinct take away points (44 pages of text).

- Hawai'i Hotel Reef Stewardship Guide (2014) https://coral.org/hotelstewardship/

VI. Examples of integrating ecological, genetic, and/or oceanographic data can be found in the following articles.

- Christie MR, DW Johnson, CD Stallings, MA Hixon (2010) Self-recruitment and sweepstakes reproduction amid extensive gene flow in a corl-reef fish. Molecular Ecology 19: 1042-1057.
- Christie MR, BN Tissot, MA Albins, JP Beets, Y Jia, DM Ortiz, SE Thompson, MA Hixon (2010) Larval connectivity in an effective network of marine protected areas. PLoS ONE 5(12).

VII. Additional Potential Data Sources:

Biophysical spatial datasets for the main Hawaiian Islands including wave energy, sea surface temperature, and surface chlorophyll provided by the Ocean Tipping Points project.
https://www.pacioos.hawaii.edu/projects/oceantippingpoints/#datasources

Fishing pressure & sedimentation spatial datasets for the main Hawaiian Islands provided by the Ocean Tipping Points project.
https://www.pacioos.hawaii.edu/projects/oceantippingpoints/#datasources

Fisheries regulations provided by the State of Hawai'i Division of Aquatic Resources.
https://dlnr.hawaii.gov/dar/fishing/fishing-regulations/gear-restrictions/

Hawai'i economic and tourism datasets available from the Hawai'i state government.
http://dbedt.hawaii.gov/economic/

Fisheries data through NOAA's Western Pacific Fisheries Information Network (WPacFIN).
https://apps-pifsc.fisheries.noaa.gov/wpacfin/home.php

Online maps could be used to find the locations of boat ramps, boat harbors, beach access points, roads, impervious surfaces, stream inputs, etc.

Suggested Modifications:

This case study includes interdisciplinary data integration. As appropriate for the course pre-requisites and course goals, module 2 could be expanded to include an additional class meeting for the students to develop and run spatial and temporal analyses.

Potentially useful statistical tutorials:

"Stats 101: Multiple regression, the very basics" from Brandon Foltz (20 min)
https://www.youtube.com/watch?v=dQNpSa-bq4M

"Stats 101: Multiple regression, evaluating basic models" from Brandon Foltz (25 min)
https://www.youtube.com/watch?v=wPJ1_Z8b0wk

Topically, this case study could be expanded to include an emphasis on highly migratory species, the high seas, enforcement challenges for managing marine resources, and aquaculture. Including these topics could be through a conversation focused on the cost and benefits of these resource extractions within the socio-environmental system or by asking students to follow up to the case study by creating a systems dynamics map focused on one of these marine issues.

References:

Christie MR, DW Johnson, CD Stallings, MA Hixon (2010) Self-recruitment and sweepstakes reproduction amid extensive gene flow in a corl-reef fish. Molecular Ecology 19: 1042-1057.

Christie MR, BN Tissot, MA Albins, JP Beets, Y Jia, DM Ortiz, SE Thompson, MA Hixon (2010) Larval connectivity in an effective network of marine protected areas. PLoS ONE 5(12).

Delaney DG, LT Teneva, KA Stamoulis, JL Giddens, H Koike, T Ogawa, AM Friedlander, JN Kittinger (2017) Patterns in artisanal coral reef fisheries revealed through local monitoring efforts. PeerJ 5: e4089.

Department of Business, Economic Development, & Tourism (2019) Research and economic analysis. http://dbedt.hawaii.gov/economic/

Division of Aquatic Resources' Fishing Regulations https://dlnr.hawaii.gov/dar/fishing/fishing-regulations/gear-restrictions/

Franklin TM, R Helinski, A Manale (2007) Using adaptive management to meet conservation goals. The Wildlife Society 07-1: 103-113. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_013594.pdf

Frédérich B, Colleye O, Lepoint G, Lecchini D (2012) Mistmatch between shape changes and ecological shifts during the post-settlement growth of the surgeonfish, *Acanthurus triostegus*. Frontiers in Zoology 9:8.

Hansen GJA, JW Gaeta, JF Hansen, SR Carpenter (2015) Learning to manage and managing to learn: sustaining freshwater recreational fisheries in a changing environment. Fisheries 40(2): 56-64.

Harold K. Castle Foundation Website http://castlefoundation.org/investments/marine/

Hawai'i Hotel Reef Stewardship Guide (2014) https://coral.org/hotelstewardship/

Jokiel PL, KS Rodgers, WJ Walsh, DA Polhemus, TA Wilhelm (2011) Marine resource management in the Hawaiian Archipelago: the traditional Hawaiian system in relation to the western approach. Journal of Marine Biology. doi: 10.1155/2011/151682.

Jones ML, GJA Hansen (2014) Making adaptive management work: lessons from the past and opportunities for the future. Taylor WW, Leonard N, Lynch A, eds. Future of Fisheries: Perspectives for the Next Generation of Professionals. American Fisheries Society, Bethesda MD.

Ke Kukulu Ahu: Aha Moku Advisory Committee Strategic Plan (2013) http://dlnr.hawaii.gov/ahamoku/files/2013/09/Ke-Kukl-Ahu-Strat-Plan-Template-DLNR.docx

Maui Coral Reef Recovery Team (2015) Ola nā Papa i Mālama ʻia: A practical plan for the technical and cultural restoration of Maui's coral reefs. Version 2.0. Maui Nui Marine Resource Council, Kīhei, Maui. https://www.mauireefs.org/

McCoy KS, ID Williams, AM Friedlander, H Ma, L Teneva, JN Kittinger (2018) Estimating nearshore coral reef-associated fisheries production from the main Hawaiian Islands. PLoS ONE 13(4): e0195840. https://doi.org/10.1371/journal.pone.0195840. https://www.fisheries.noaa.gov/science-blog/how-many-fish-are-being-caught-reefs-near-shores-hawaii

Mohan M, CSG Pillai (1988) The biology of the convict surgeonfish *Acanthurus triostegus triostegus* (Linnaeus) from Minicoy Atoll, Lakshadweep. J. mar. boil. Ass. India 30: 182-191.

Otwoma LM, V Diemel, H Reuter, M Kochzius, A Meyer (2018) Genetic population structure of the convict surgeonfish *Acanthurus triostegus*: a phylogeographic reassessment across its range. Journal of Fish Biology 93(4). https://doi.org/10.1111/jfb.13686

PacIOOS Website https://www.pacioos.hawaii.edu/projects/oceantippingpoints/#datasources

Randall JE (1961) A contribution to the biology of the convict surgeonfish of the Hawaiian Islands, *Acanthurus triostegus sandoicensis*. Pacific Science XV.

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Acknowledgements: This work was supported by the National Socio-Environmental Synthesis Center (SESYNC) under funding received from the National Science Foundation DBI-1639145. This work was influenced by C. Counsell's ongoing work with the Hawaiʻi Monitoring and Reporting Collaborative and through conversations with partners at the Division of Aquatic Resources for the state of Hawaiʻi and the Harold K. L. Castle Foundation.