
MANAGING FOR ISLAND RESILIENCE THROUGH SCENARIO PLANNING WITH LINKED LAND-SEA MODELS
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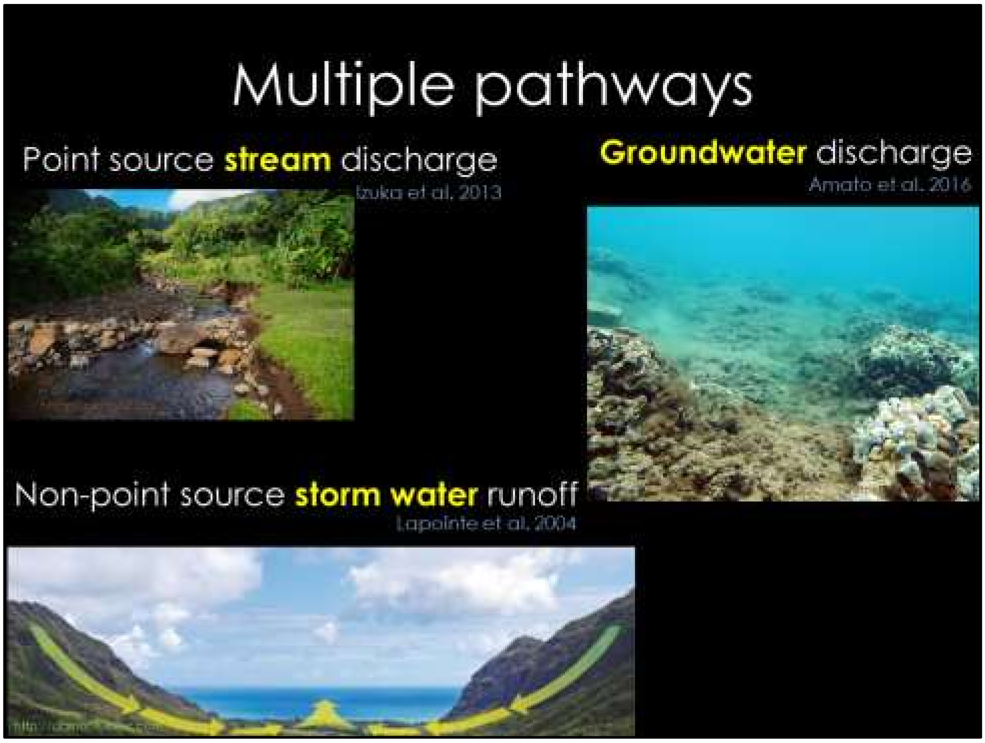
Around the world,
Coral reefs are threatened by climate change through bleaching
While Growing population
increase pressure on local natural resources through

Higher demand for food resulting in
Higher fishing pressure and the loss of herbivores
While coastal development increases land based source nutrients discharge
Which fosters algae growth

The declining state of our natural resources has contributed to a cultural renaissance
Around the Pacific, local communities seek to revive local and place-based management
Such as the customary ridge-to-reef management approach
Traditional closures
and sustainable practices
to foster social and ecological resilience

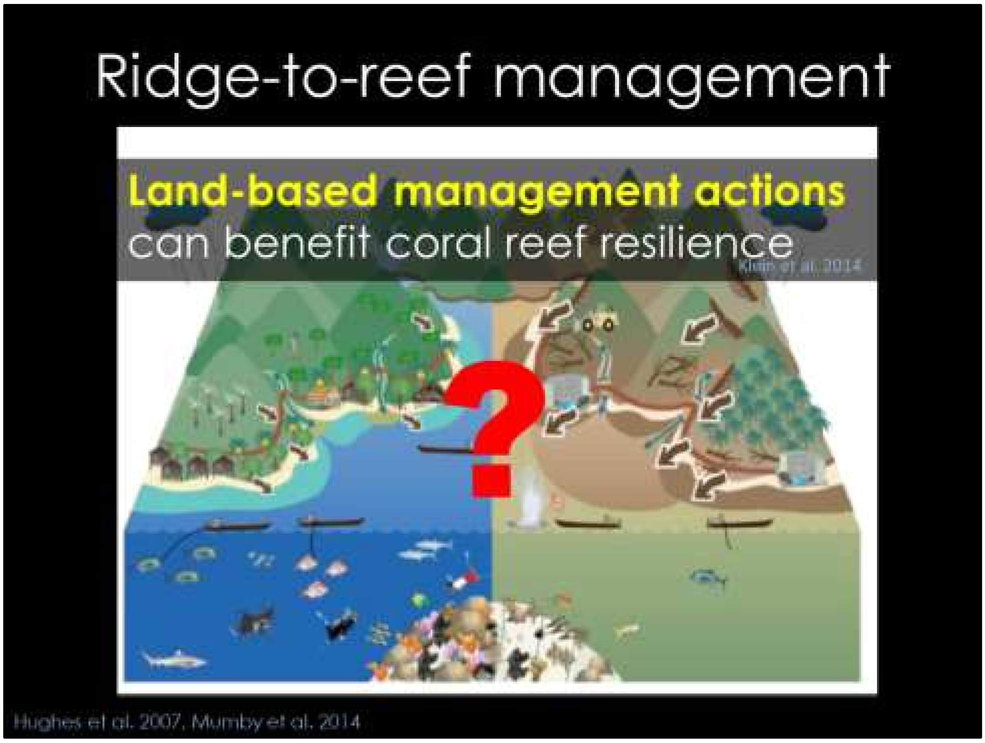
Pacific islands have a volcanic origin and are very susceptible to natural disturbances
They are exposed to rainfall gradients, which carve steep topographical relief while
Fringing coral reefs are sculpted by powerful oceanic swells

As a result of their small size and steep elevational gradients
Land and sea are tightly connected through social and ecological processes

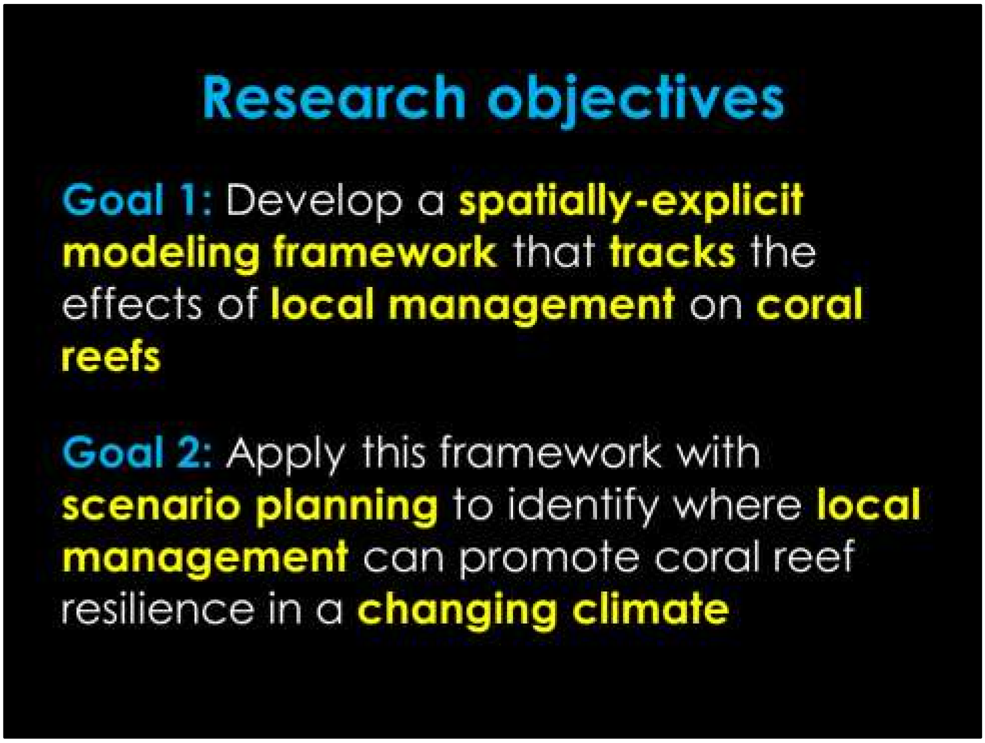


Which take multiple pathways to the ocean
Ranging from streams
To storm water runoffs
And less studied but as important on oceanic islands, groundwater

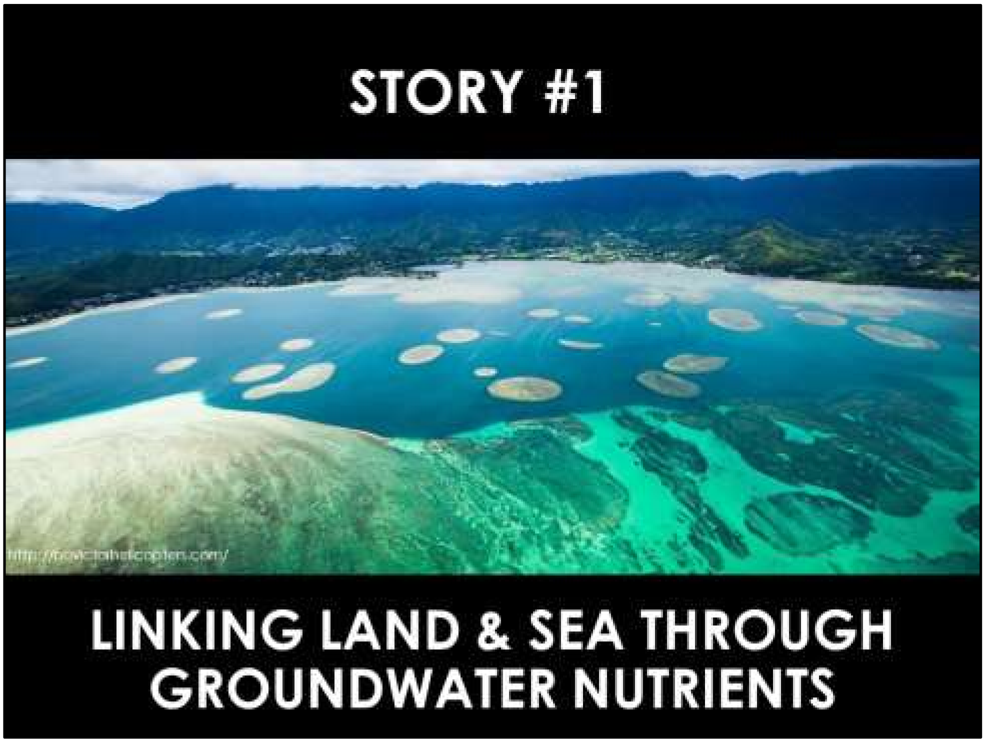
Marine closures have been shown to protect CR from direct threats, such as fishing pressure
However they have also been shown to fail in the absence of social buy in
Or when exposed to LBSP, like sedimentation



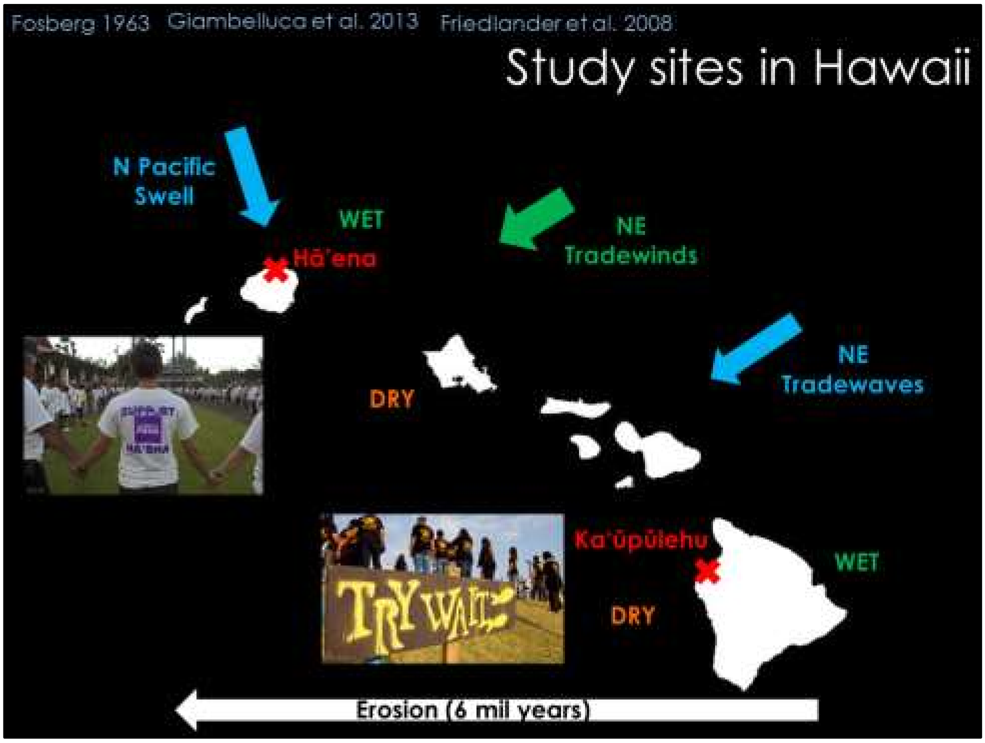
Therefore, land based management that account for downstream impacts has been widely advocated to foster CR resilience
But determining where and how to manage the land as a function of coral reefs **can be hard to track and differs among places**



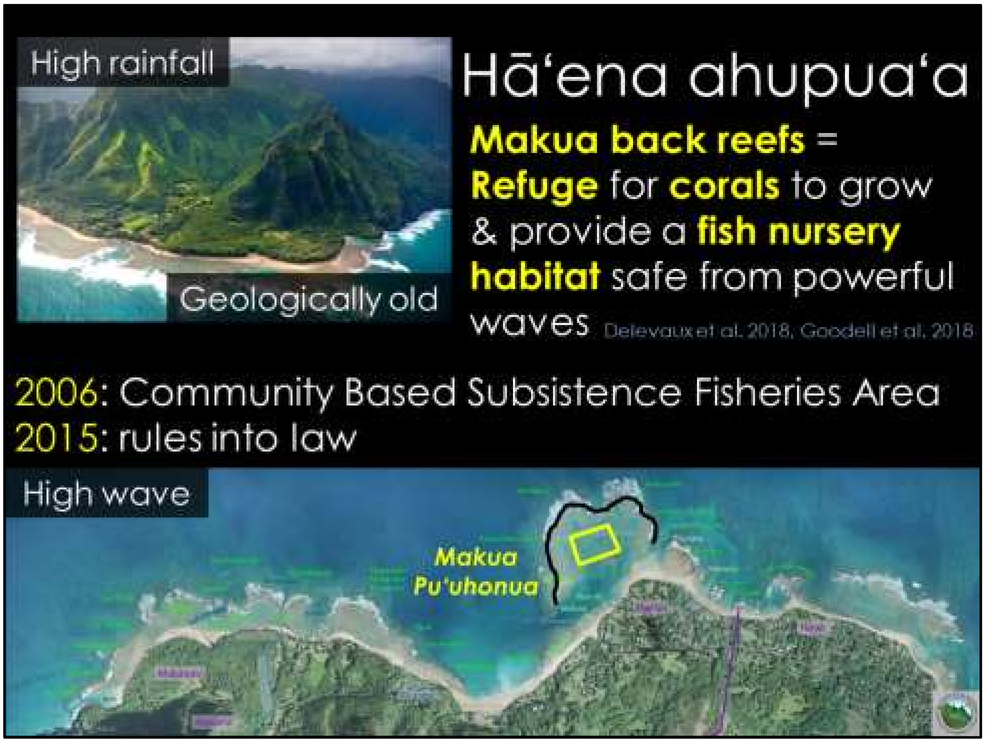
To support communities seeking to restore ridge to reef management,
We developed a spatially explicit modeling framework that tracks the effects of local management on coral reef
Then we applied this framework with scenarios to identify where local management can promote CR resilience in a changing climate
For this talk I am going to present 3 stories we weaved together



The first story is about how we linked land and sea through GW nutrients in HI

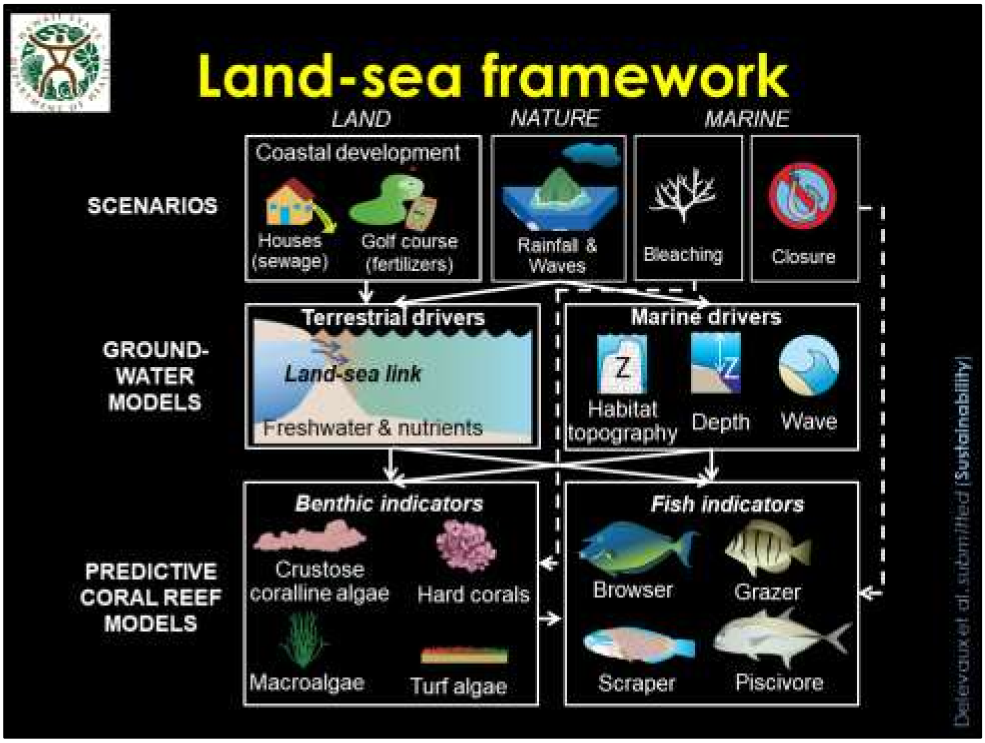


where 2 native Hawaiian communities embody this cultural renaissance
Hāʻena, located on the windward side of Kauaʻi Island
Kaʻūpūlehu, located on the leeward side of Hawaiʻi Island
Due to their location at the opposite ends of the MHI, those places span over 6 m years of erosion
The wind patterns coupled with the rain shadows from the high shield volcanoes results in windward side being wet and the leeward side being dry
Due to their location in the middle of the Pacific Ocean,
Haena is exposed to very large open oceanic swells while Kaupulehu is sheltered



Due to its old geological age & exposure to the tradewinds, Haena receives high rainfall which carved steep cliffs
The exposure to large oceanic swells has shaped wide and shallow reefs, such the Makua reef
In 2006 Haena was designated a CBSFA
In 2015 their rules went into law, this was the 1st time in that the U.S. state of Hawaiʻi recognized local-level fisheries management rules based on indigenous Hawaiian practices.
Among these rules, Makua back reef was designated a marine refuge where corals are able to grow and provide a fish nursery habitat safe from the powerful winter swells

The same year Kaupulehu initiated a law implementing a 10-year fishing rest period known as 'Try Wait', this resulted in the protection of the entire coral reef area
Geologically younger and located in the rain shadows of Mauna Kea & Mauna Loa, the shield volcano has not eroded as shown by its dome shape
Sheltered from large winter swells, the fringing reef is a narrow band
Ka'ūpūlehu is more developed than Ha'ena and is owned by the Kamehameha Schools



These local communities are also interested in a better understanding of how land-based sources of pollutants from golf courses, lawns and cesspools affect their marine ecosystems.

Given groundwater was the main vector for land based nutrients at both sites, we modeled groundwater,

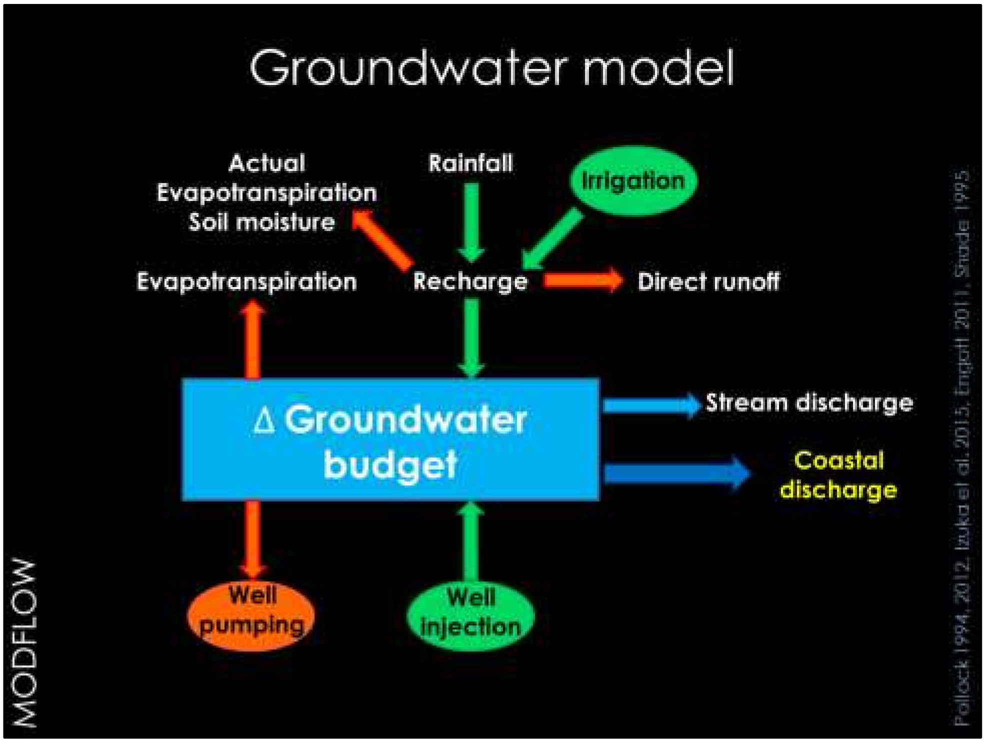
Here I want to acknowledge DOH for providing land use and GW data

We used existing marine data to characterize the marine habitat at both sites

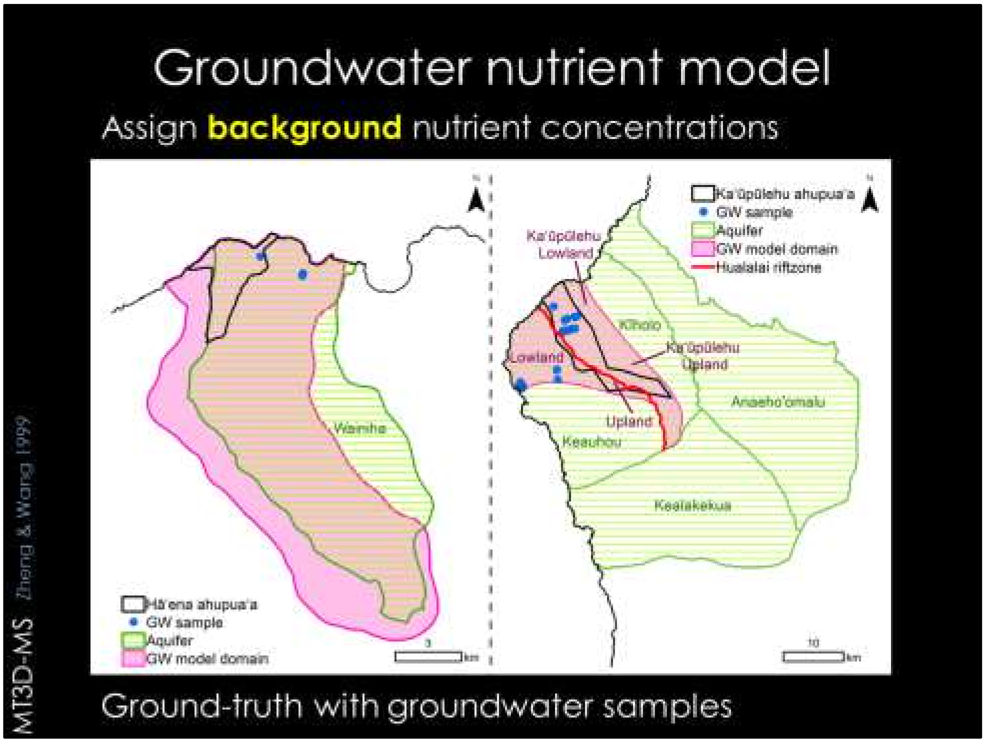
And modeled the effects of nutrients and marine habitat on benthic and fish indicators

I want to acknowledge FERL and TNC for providing the CR data to calibrate our models

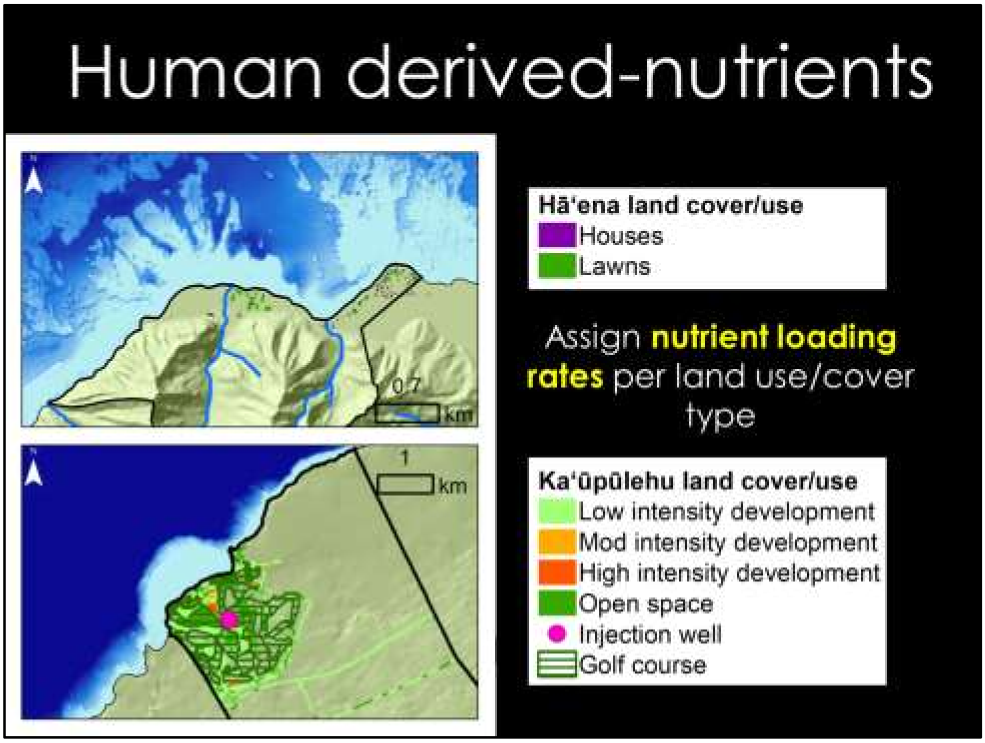
Once calibrated, this framework can be coupled with place based scenarios



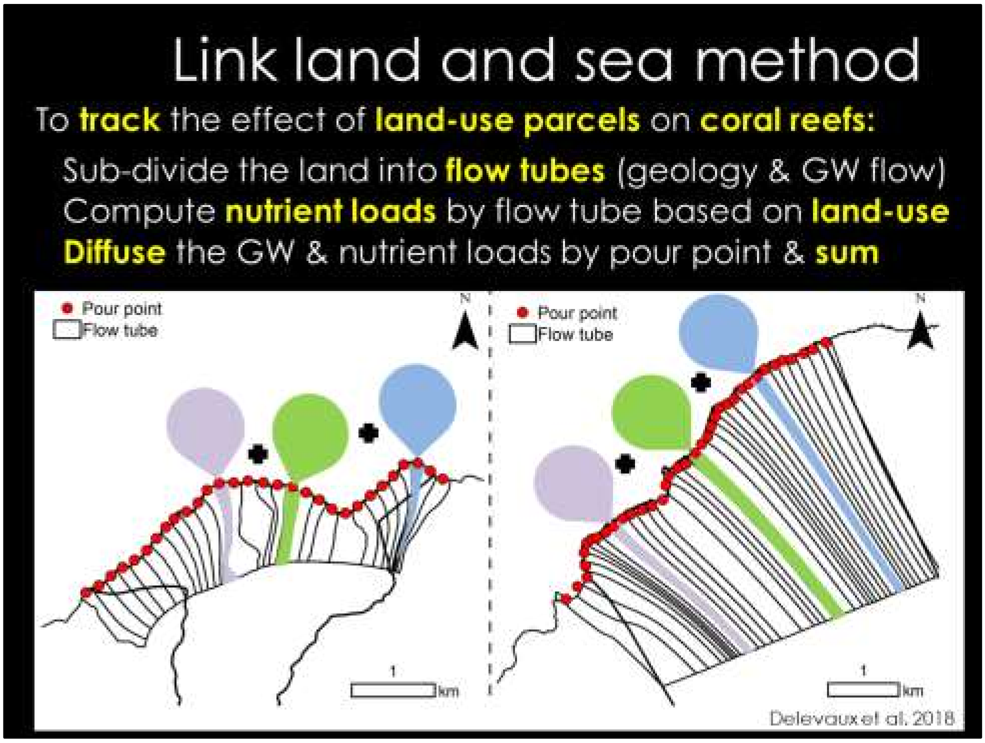
We parameterized the GW flow model (MODFLOW) based on what comes out of the aquifer, in terms of ET and pumping
And how much comes in in terms of Recharge and injections.
We quantified the stream and coastal discharge
When GW R is not available, as it was the case at Haena,
we computed the GW R,
based on what comes in (rainfall & irrigation)
& what comes out (AET, SS, & DR)



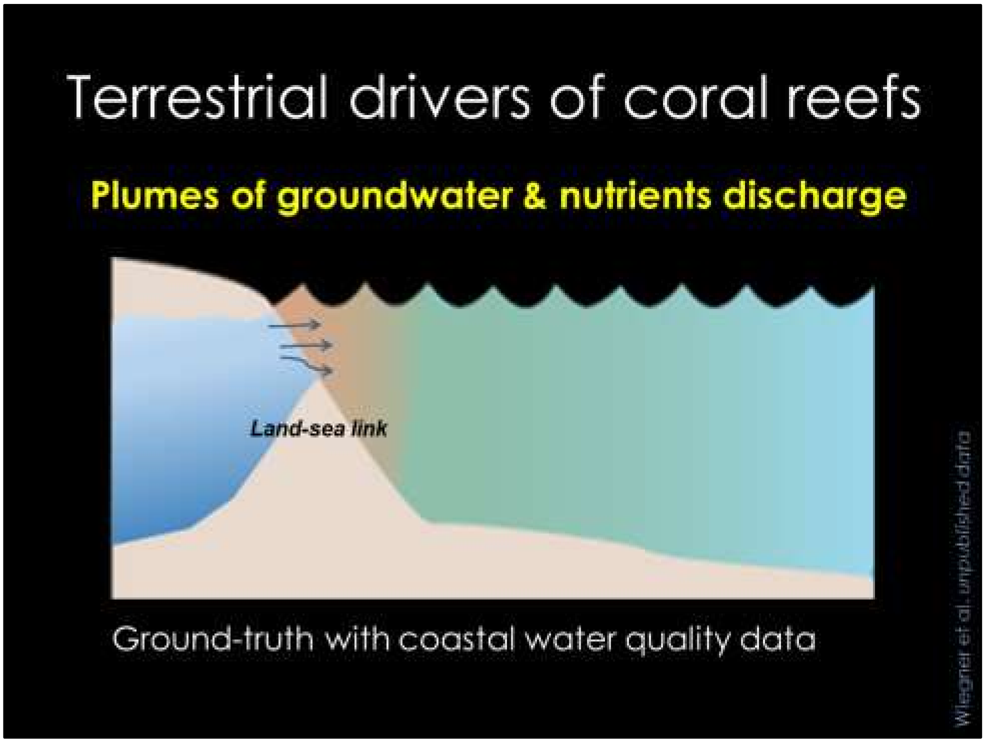
For the nutrient flux model, we modeled the total inorganic nitrogen and phosphorus loads
We assigned representative nutrient concentrations to the groundwater recharge
& We used existing GW sample data, when possible to ground-truth these models



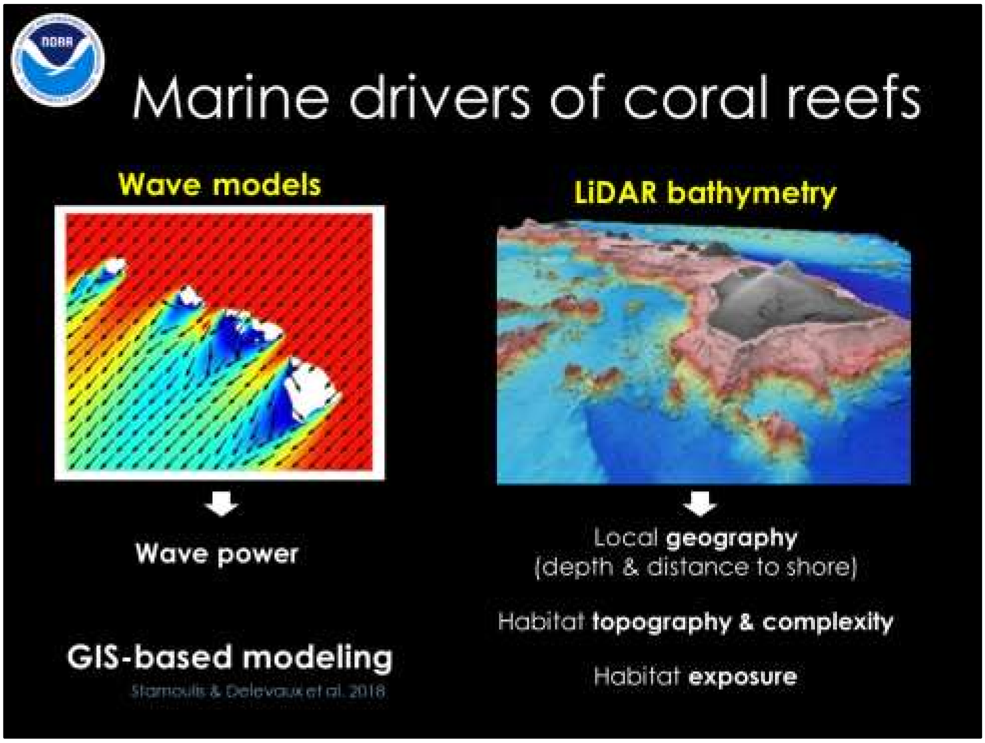
To model the anthropogenic drivers,
We assessed the land cover/use using aerial images & state databases
Then we assigned nutrient loading rates per land use/cover type
Which was added to the background nutrient concentrations.



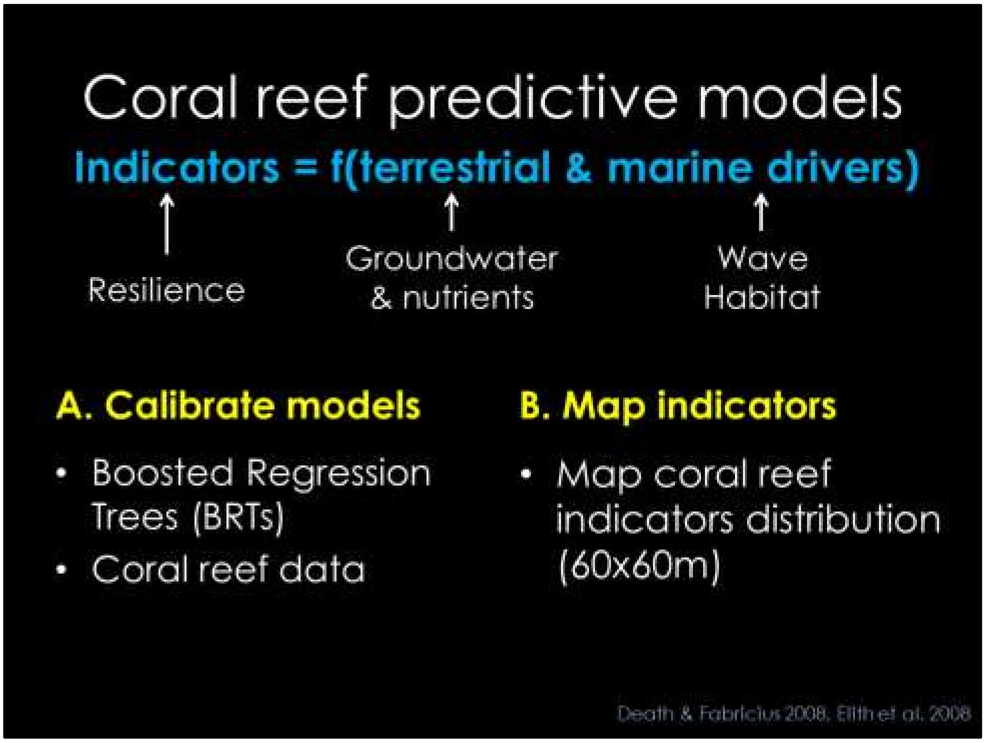
To track the effect of land-use parcels on coral reefs:
We sub-divided the landscape into flow tubes
Compute the nutrient load by flow tube
Diffuse the GW & nutrient loads by pour point w simple GIS models
Combine all those individual plumes



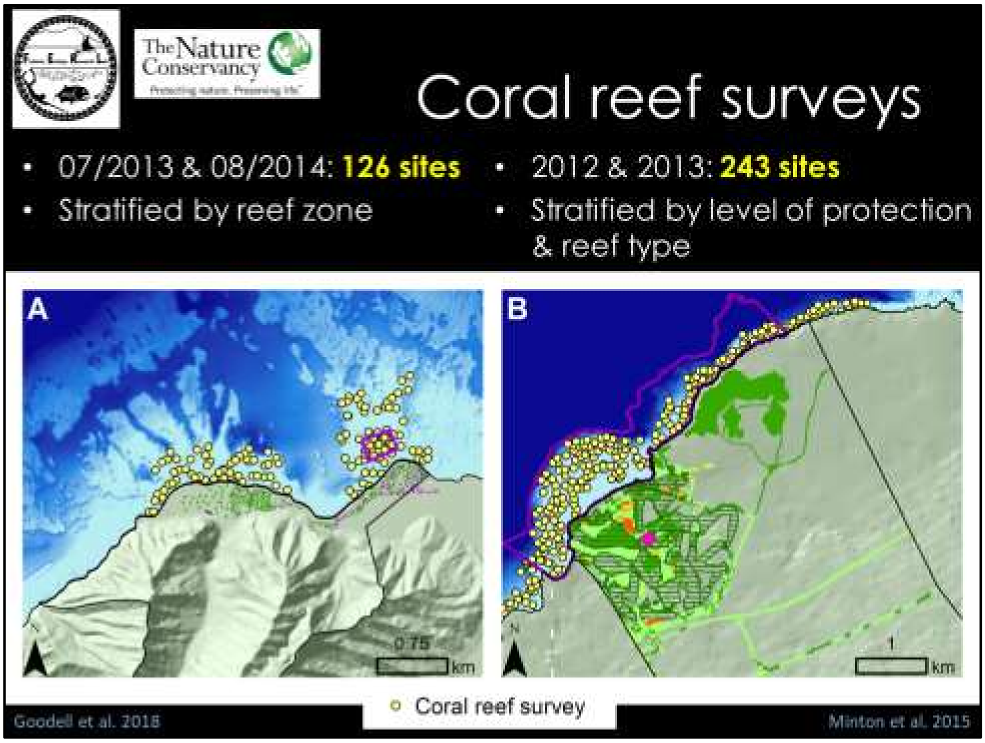
Combine the individual groundwater & nutrient plumes…
to generate the plumes of groundwater and nutrient discharge
Use existing coastal water (CW) samples to ground-truth these models



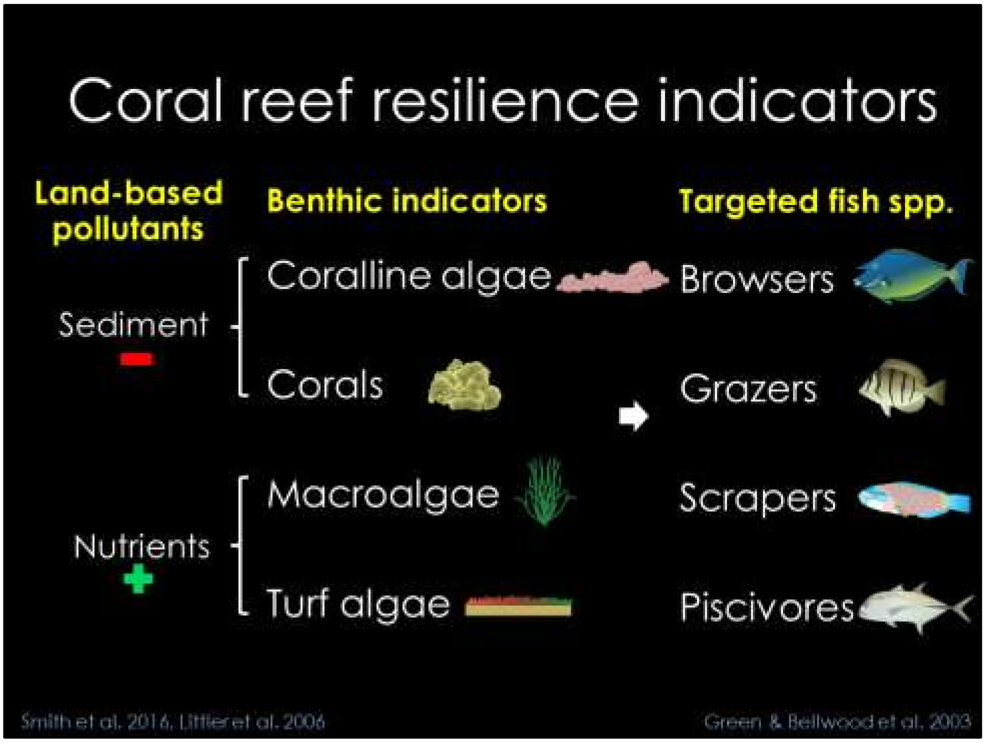
We used the SWAN wave model to derive wave power at both sites
And Lidar bathymetry coupled with GIS models to derive metrics of habitat conditions at both sites



For the CR models,
We modeled CR indicators as a function the terrestrial and marine drivers
The indicators represent dimensions of coral reef resilience
The terrestrial drivers represented the GW discharge
The marine drivers represented wave power, habitat and local geography
We calibrated the coral reef models with empirical data
to establish the relationships between reef indicators and drivers
Then we used those calibrated models to predict and
map the distribution of each indicator at 60 m resolution across the model domain

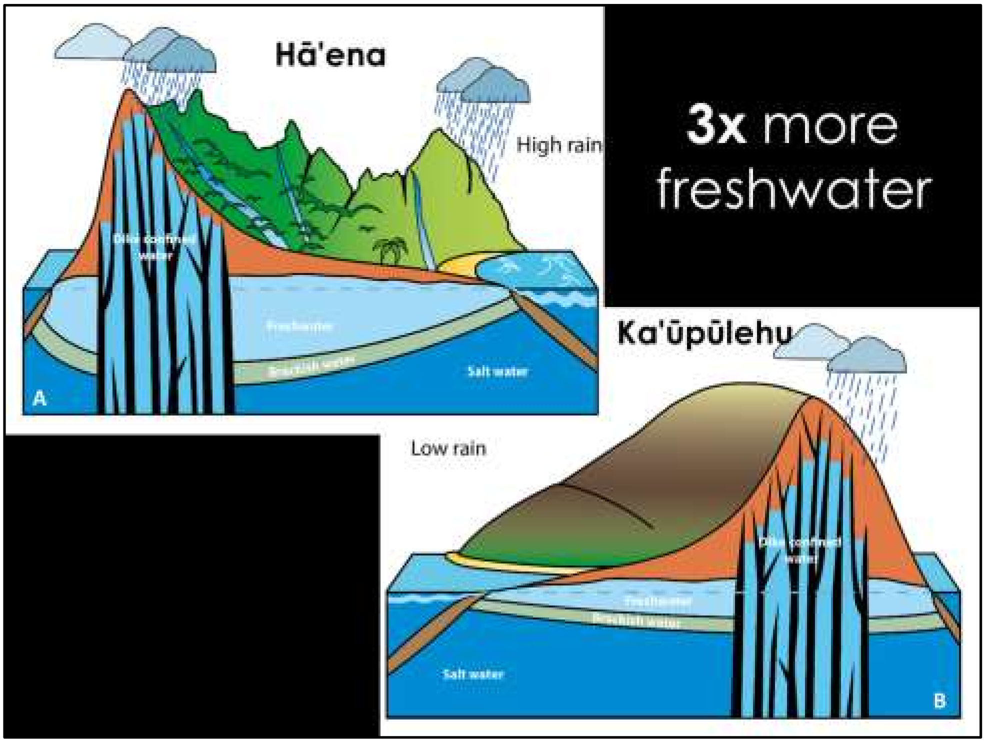


We used a dataset provided by FERL for Haena and totaling 126 sites
And a dataset provided by TNC for Kaupulehu – totaling 243 sites
From these datasets we derived our benthic and fish indicators for the modeling

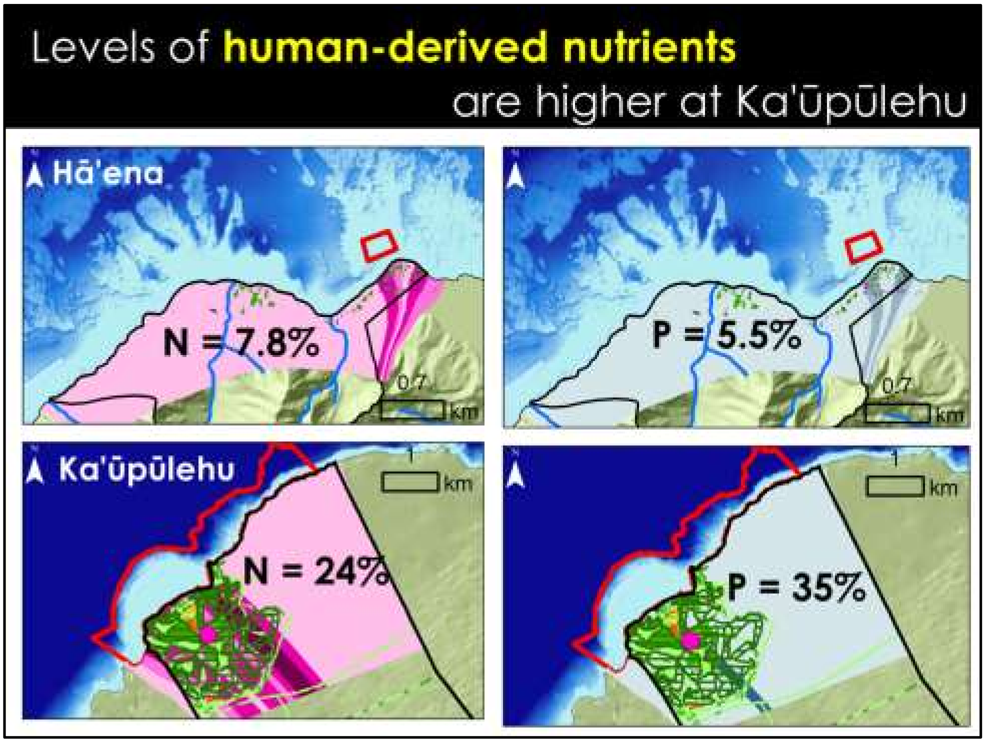


Our coral reef resilience indicators consisted of 4 benthic indicators known to respond to change in sediment and nutrient runoffs [CLICK]
Which in turn shape the habitat that coral reef fish spp are dependent on.
We focused on targeted spp by local communities and classified them by their functional role for modeling

First I will compare and contrast the baseline conditions for each site

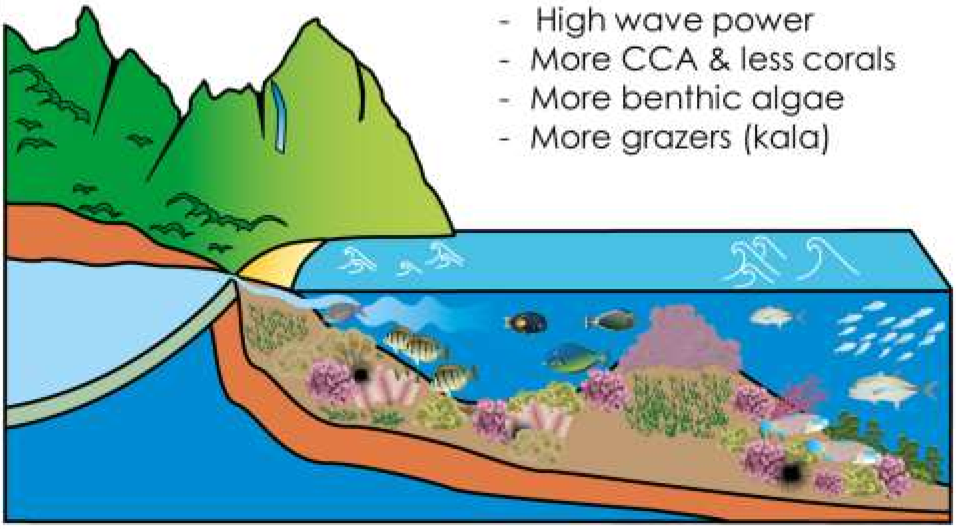


Haena also benefits of dilution from higher GW recharge,
Reflecting the high rainfall at Haena and the dry conditions of Kaupulehu
& resulting in nearly 3 times more GW discharge at Haena compared to Kaʻūpūlehu



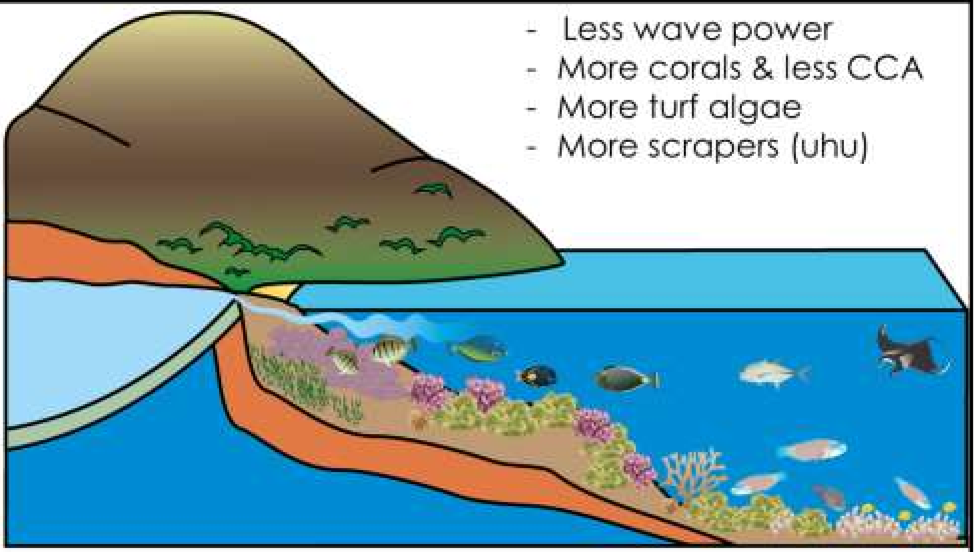
Levels human-derived nutrients ar higher at Kaupulehu compared to Haena

Hā'ena coral reefs

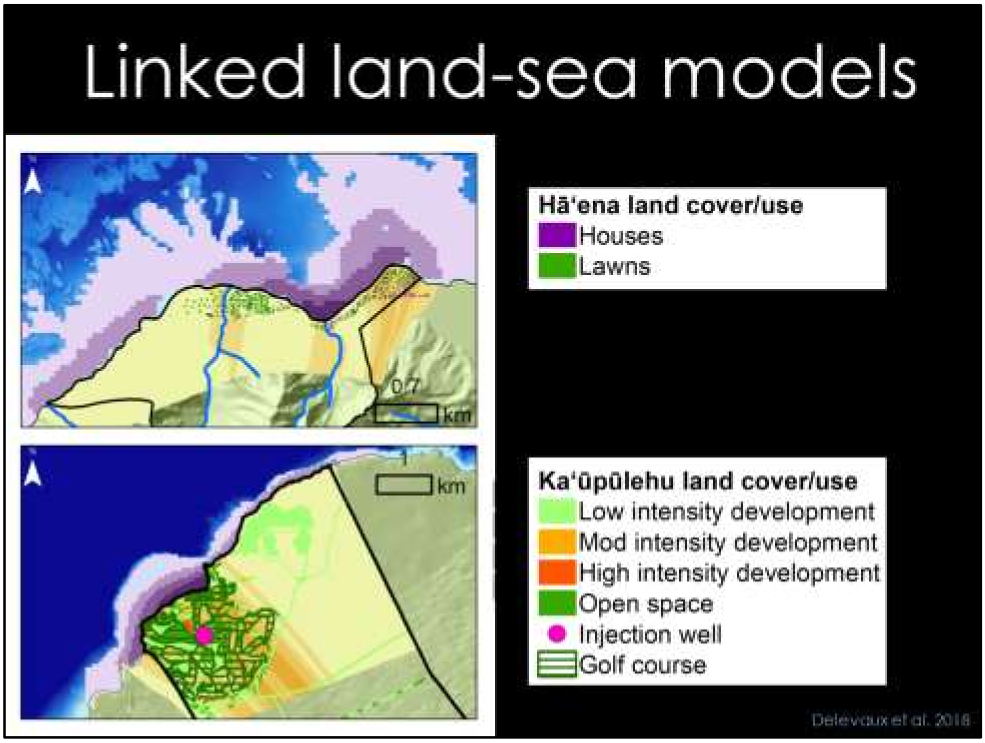


- High wave power
- More CCA & less corals
- More benthic algae
- More grazers (kala)

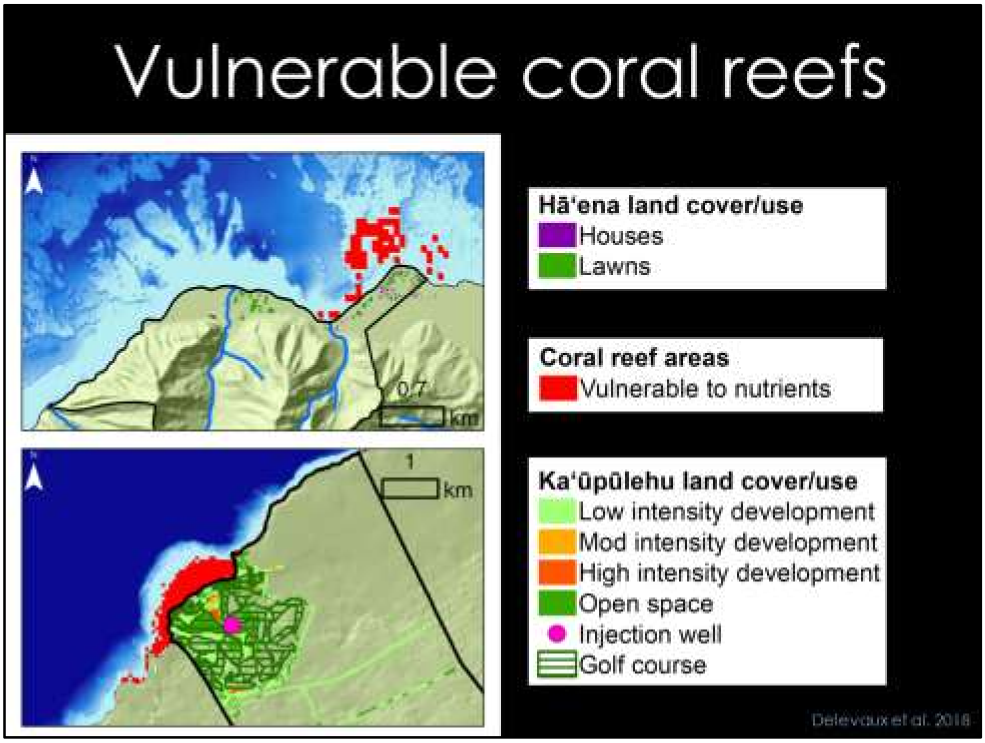
Ka'ūpūlehu coral reefs



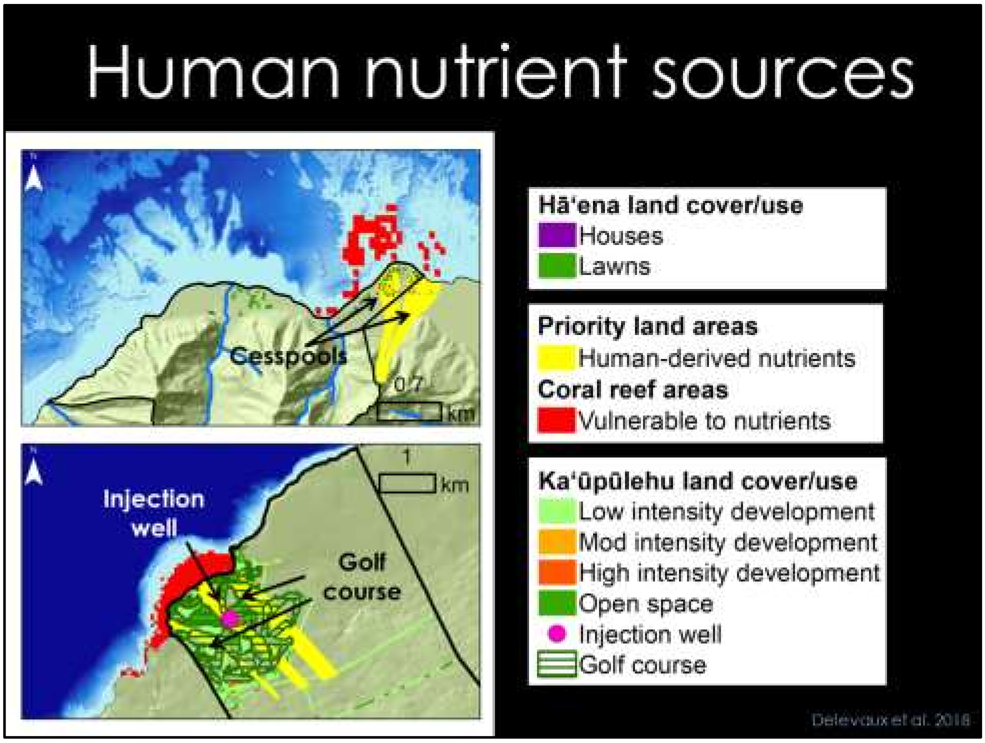
The second story is about how this tool can inform ridge-to-reef management [CLICK]



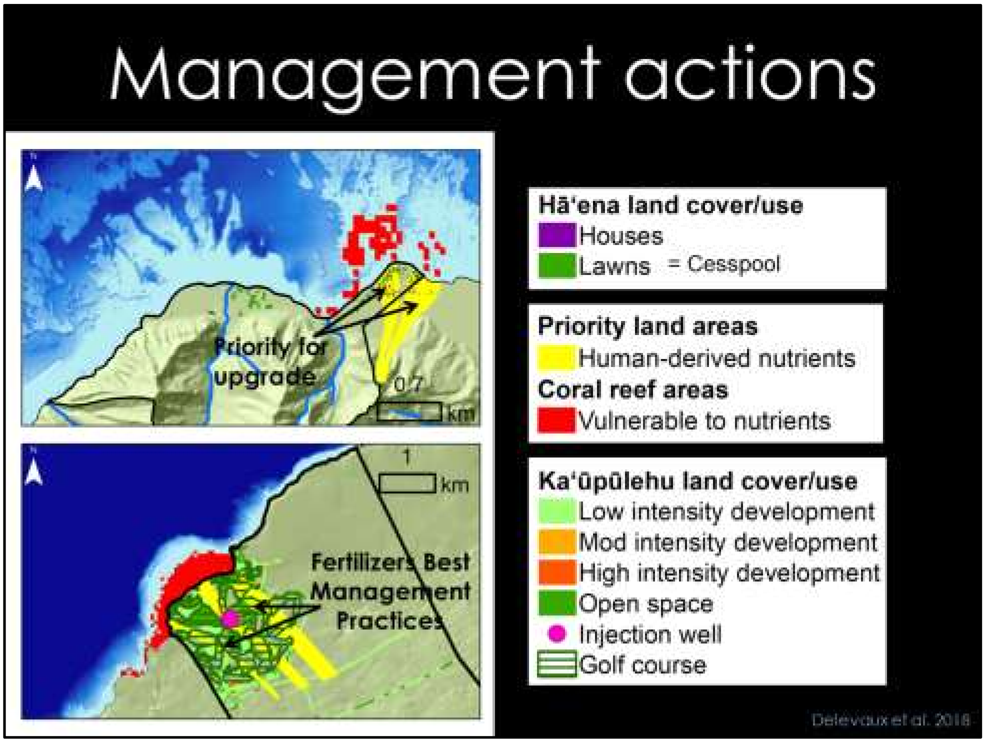
Under present land use
There is about 100 houses in purple with some lawns along the shore at Haena
While Kaupulehu has a golf course, 2 luxury resorts with an injection well shown in pink, and several private residences
Our land sea models indicated a higher nutrient discharge to the East of Haena – shown in darker purple
And the south in Kaupulehu [CLICK]



Based on our coral reef indicators distribution and sensitivity to nutrients, we identified vulnerable coral reef areas – shown in red [CLICK]



Our groundwater models identified areas where human derived nutrients was at its highest – shown in yellow [CLICK]
With the main source being cesspools at Haena [CLICK]
And the golf course and the injection well at Kaupulehu [CLICK]



At Haena, cesspools located in the yellow zone are priority for upgrade to septic tanks [CLICK]
At Kaupulehu, BMPs for fertilizers should be maintained in the yellow zone [CLICK]

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https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0193230

RESEARCH ARTICLE

A linked land-sea modeling framework to inform ridge-to-reef management in high oceanic islands

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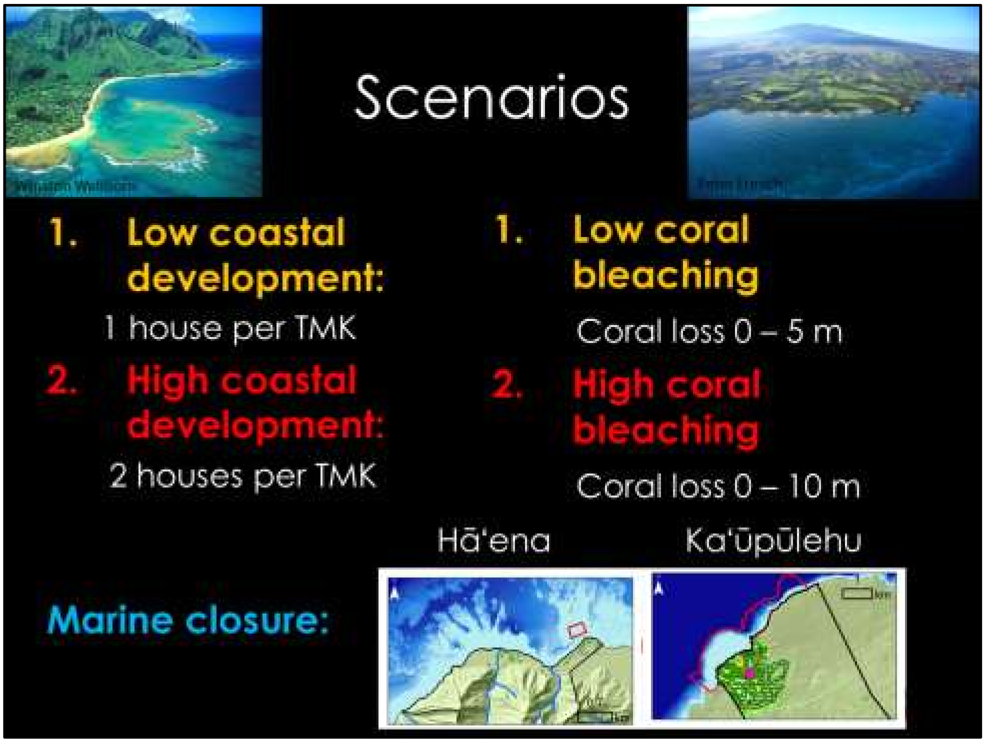
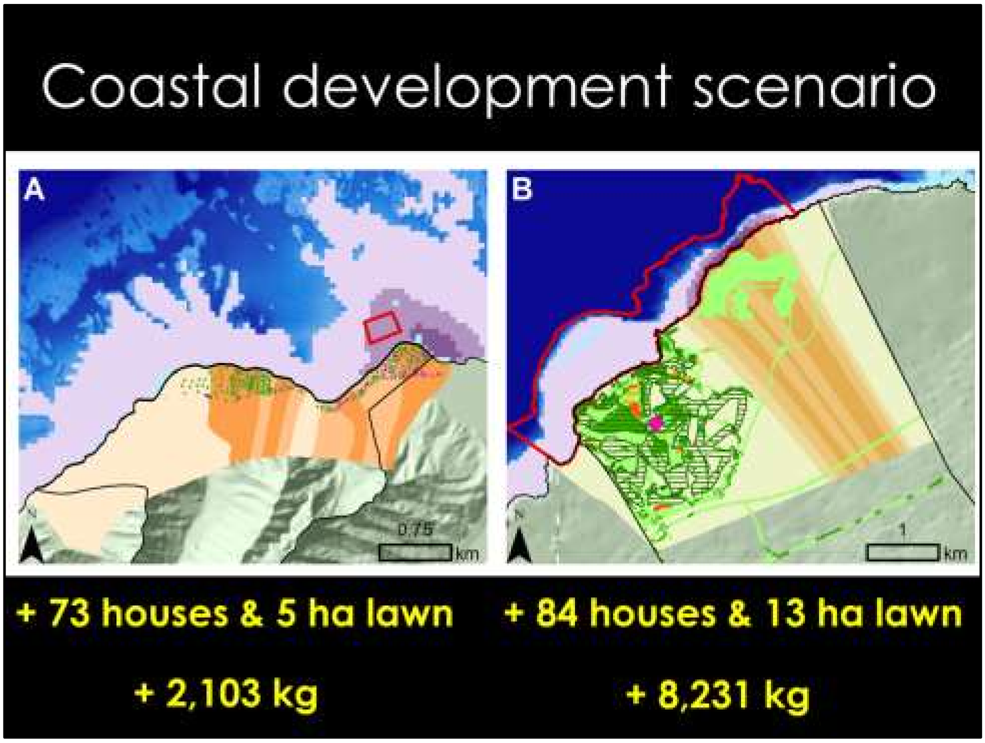
1 of the 3 papers coming out of this work was just published in PlosOne

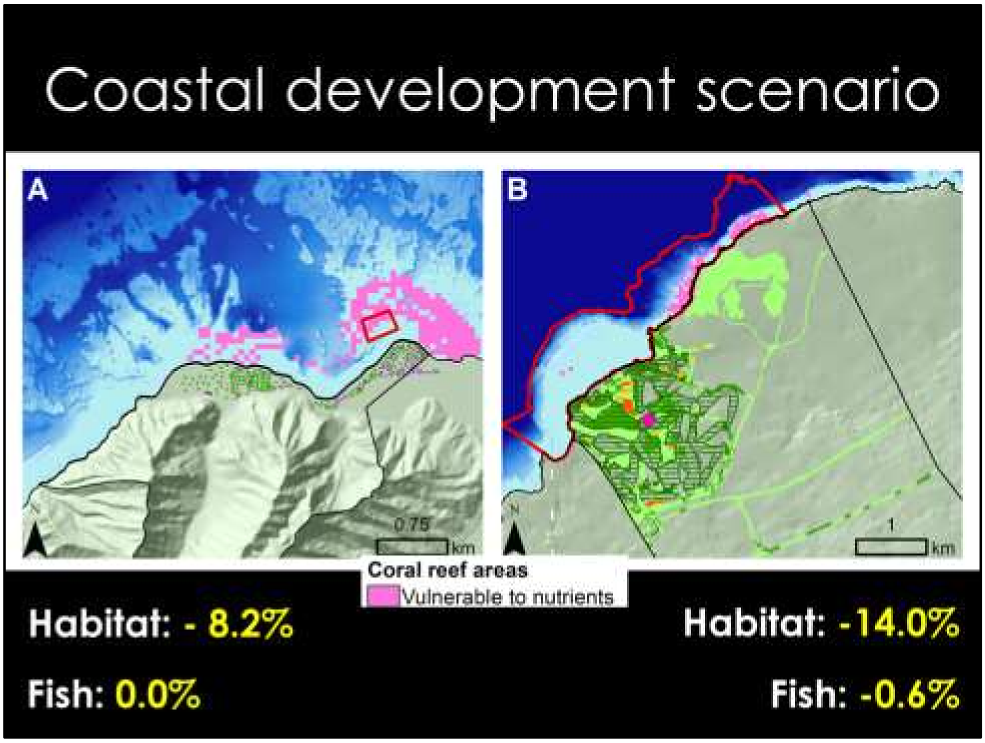
Our third story focused on how future changes can impact coral reefs



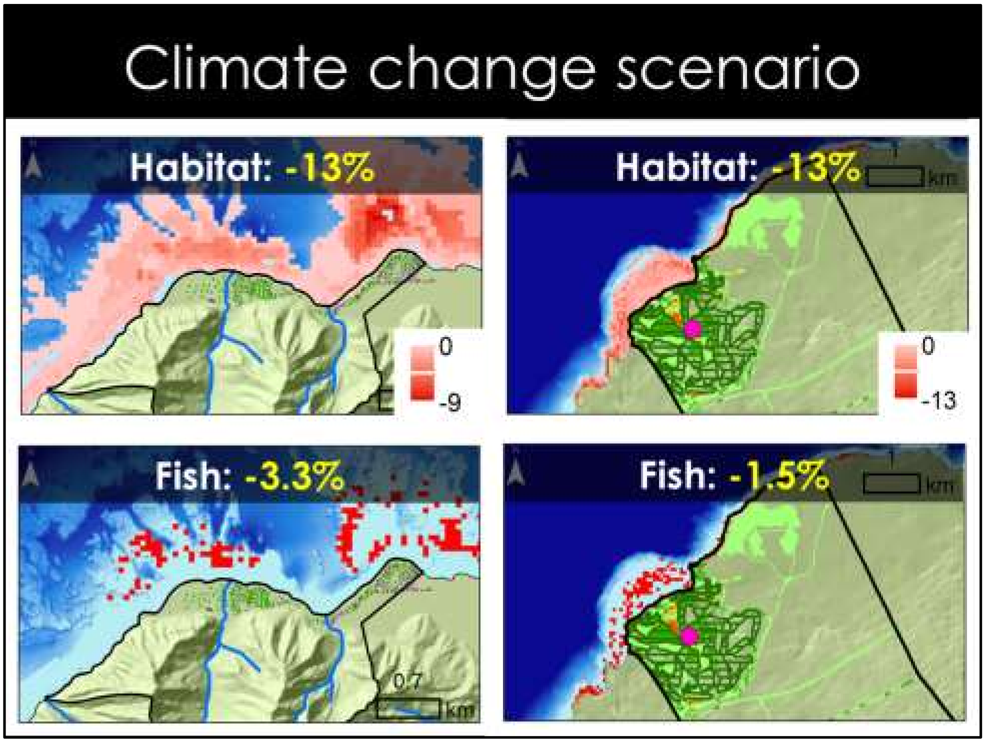
The communities were concerned about increase in coastal development impacts.
So we considered a low and high coastal development scenarios based on current land zoning
The communities were also concerned with climate change so we designed a low and high coral bleaching scenario based on projected impacts by regional models
We also looked at how the enacted marine closures could help counter act those impacts.



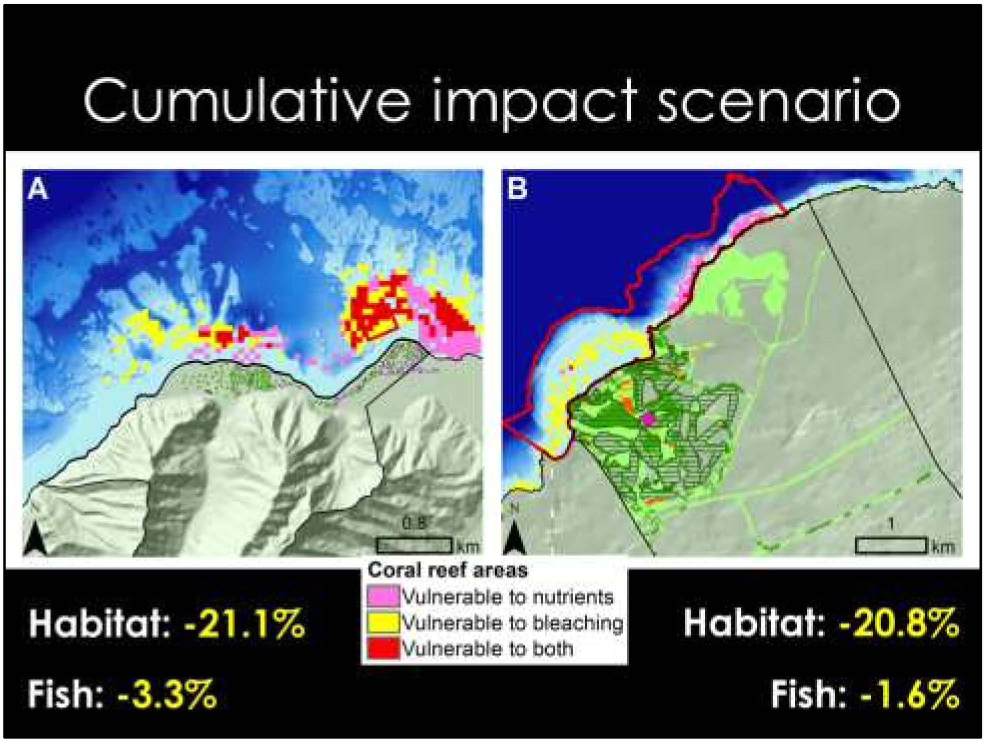
Under the High coastal development scenario,
our GW models showed an increased in nutrient, particularly in areas in the dark purple areas



Our coral reef models showed a significant habitat loss
Corresponding to a fish loss at Kaupulehu down stream from the proposed development
And a shift in the fish community in the backreef of Makua at Haena



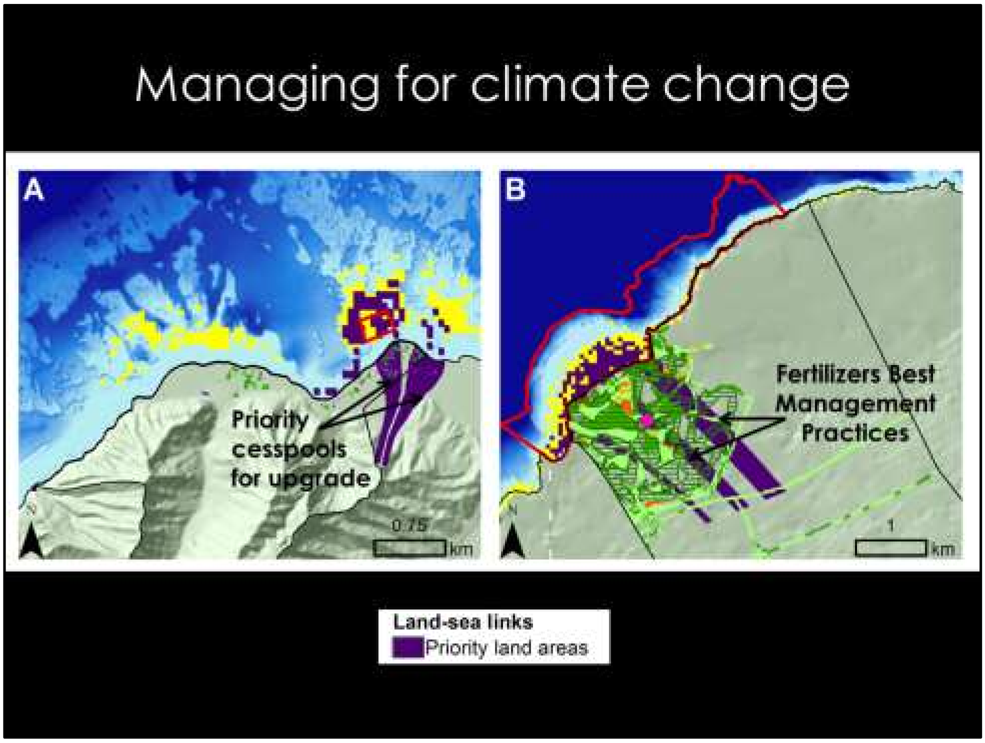
Although climate change is a global process it has local impacts, which can differ by place
So we designed 2 coral reef scenarios based on projected climate change impacts for the region
Under the high coral bleaching scenario, our coral reef models showed a significant loss of coral cover over 13% of the modeled area,
ranging from 0-9% at Haena and 0-13% at Kaupulehu
Corresponding to a 3.3% loss of the present fish biomass at Haena and 1.5% at Kaupulehu



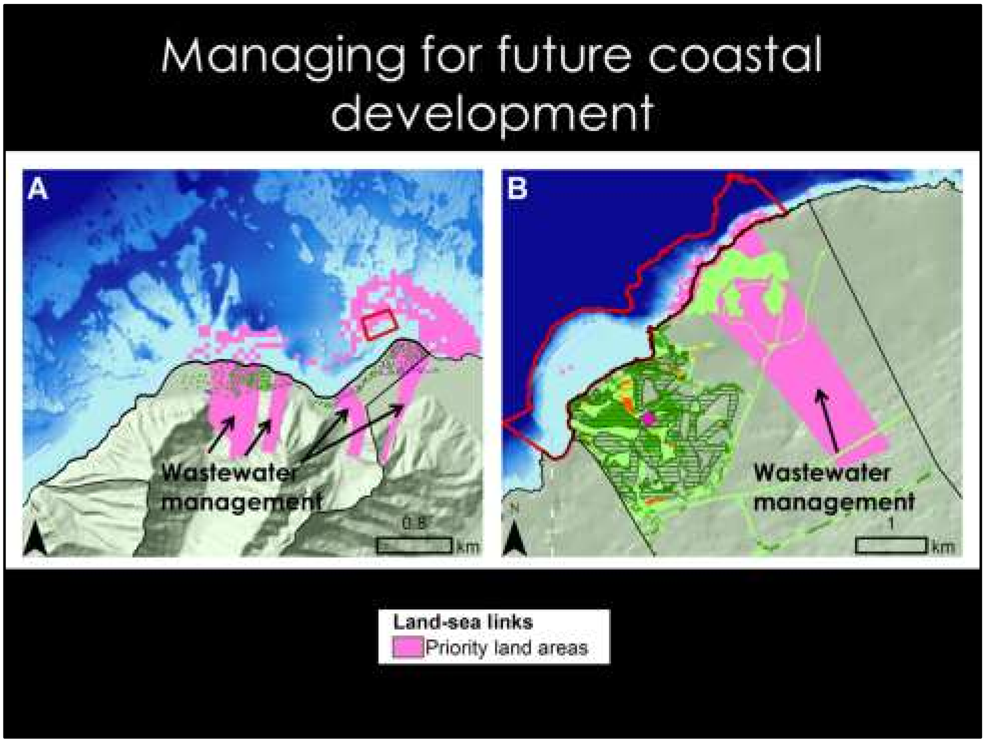
When combining the location of coral reefs vulnerable to coastal development and climate change

Coral reefs vulnerable to both do not overlap at Kaupulehu

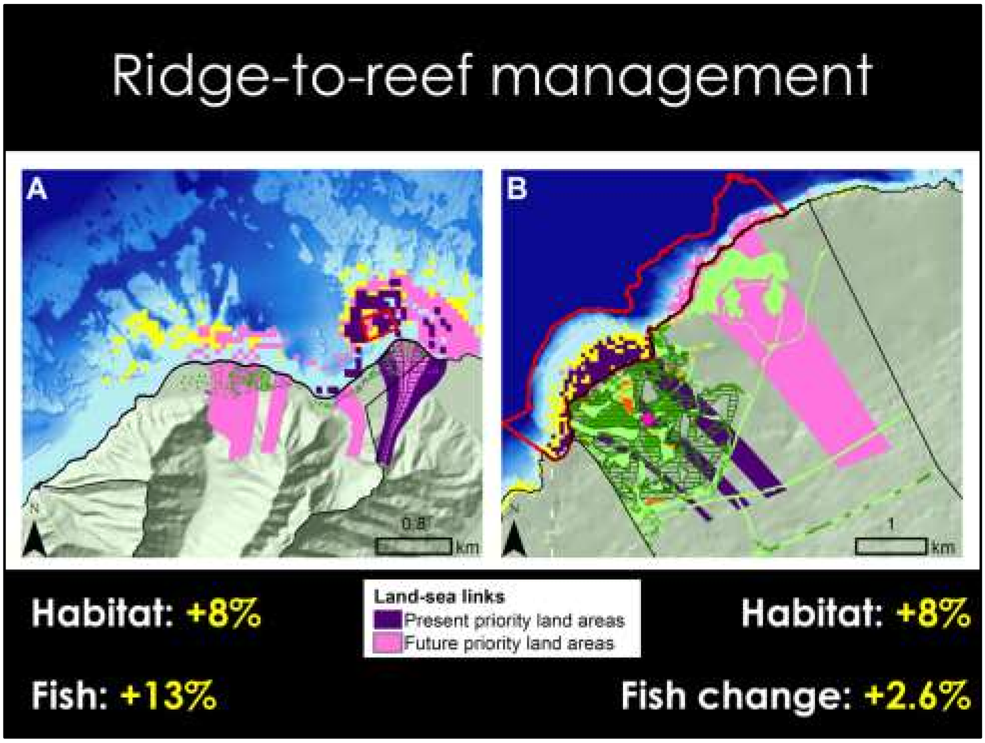
While the shallow backreef of Makua at Haena is vulnerable to both stressors due to limited wave mixing



Given climate change is coming – managing current land use in those areas will help build CR resilience

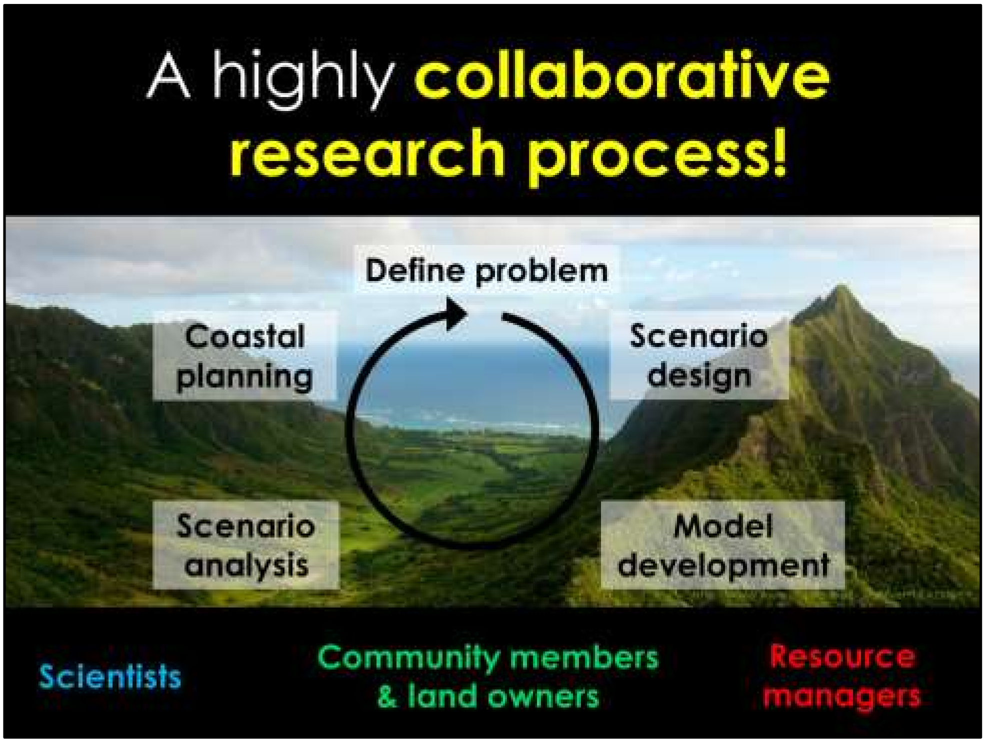


If DVMT is allowed moving forward – it is important to consider wastewater management technologies used in those areas



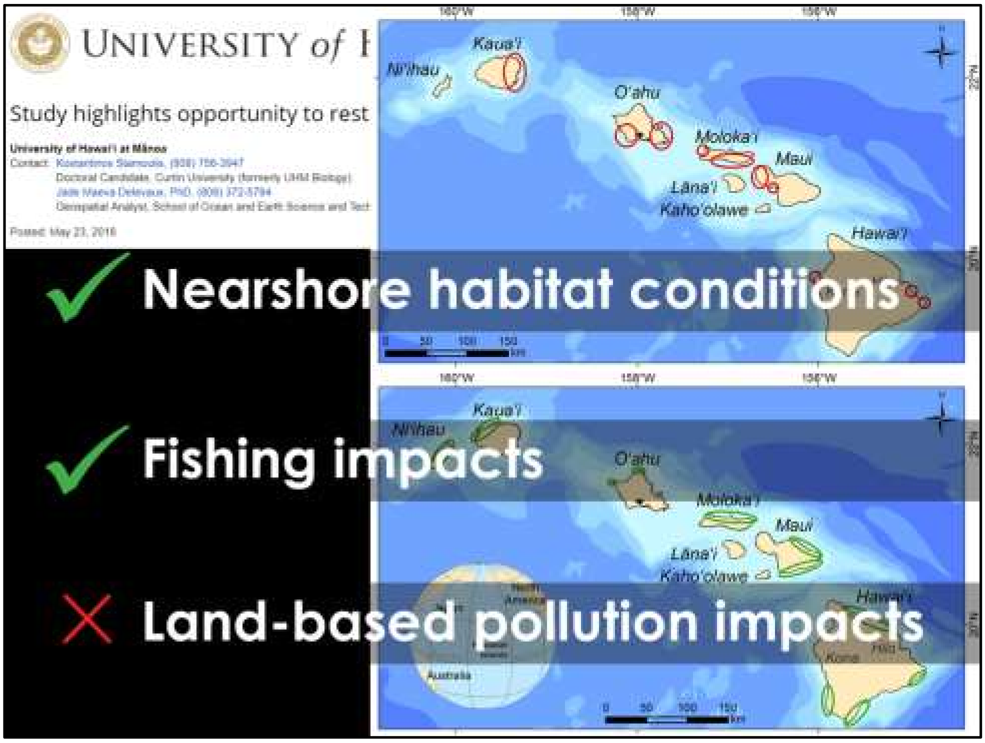
Given climate change and coastal development tend to co-occur…
These results highlight that adopting local management can benefit both places!
Land-based management improves the habitat conditions by preventing increases in benthic algae, which promotes coral recovery from bleaching within & outside the marine closures
We can also note here that areas that would benefit from land-based management are also vulnerable to bleaching. Meaning this would help with climate change impacts
While the marine-based management increases the herbivore population within the reserves, which can supplement adjacent reef through spillover

So looking across all these stories, we learnt that

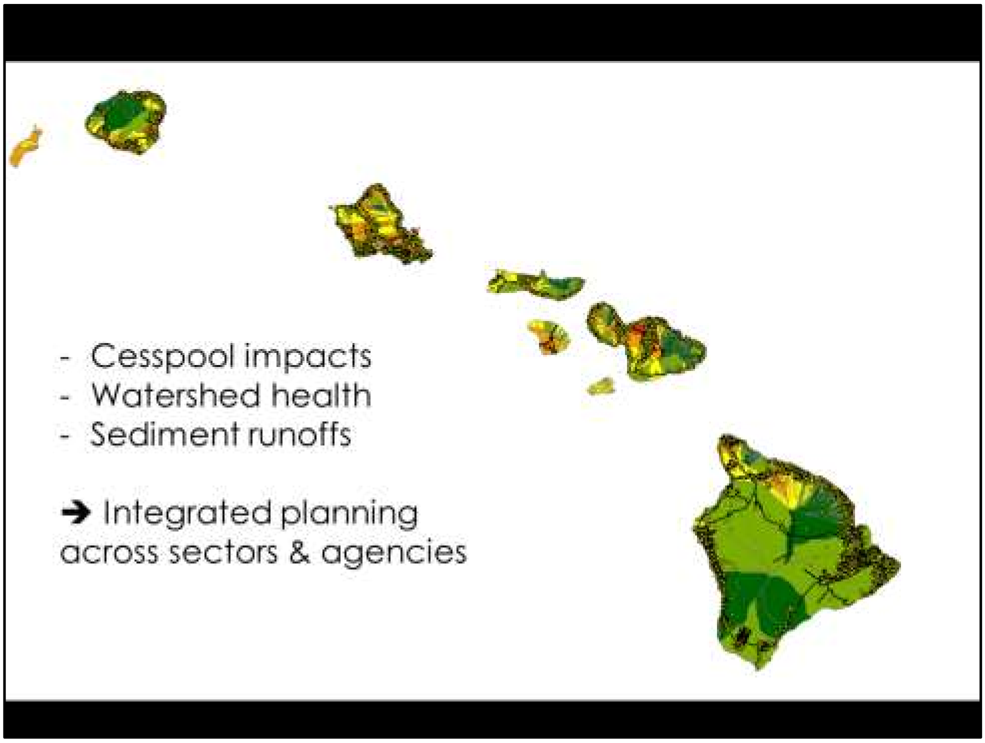


From the onset of this work –establishing a highly collaborative process amongst Scientist / land stewards and Managers was essential in the development and application of this scientific tool

Through collaborative science, which brought together communities, scientists, & managers, we produced **transdisciplinary & applied research**
We build a linked land-sea decision support tools
Which can supports **place-based management** by informing **where** on land **local management** can best benefit **coral reefs**
So our next steps is to scale up our effort to the MHI



I co-led a study that was recently published
where we identified the places where to focus fisheries management based on nearshore habitat quality and fishing pressure across the state
But we did not account for the effects of land-based pollution impacts



I would like to update these models using our land-sea framework to link the effect of cesspools, watershed health, and sediment runoffs on coral reefs.
To identify coral reef areas vulnerable to and based activities
And using our approach we can then track back land-use practices in the watershed driving this impact.

On that note, I would like to take this opportunity to thank my teachers and the community members who inspired and guided this work
As well as our research collaborators and data providers who made this work feasible

In particular Bob Whittier – my modeling partner.

Mahalo to my funders, collaborators, community and land owner partners, and data providers

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