Thirty years of changes in the benthic algal community in Kane‘ohe Bay, and the possible role of green sea turtles

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It is easy to lose sight of how much the benthic community in Kaneohe Bay has changed in the last 40 years, and consequently to ask why it has changed

Will retrace how the Bay's algal communities have changed over time and where green turtles may have been involved in these changes

The Bay is evidently one of the important feeding sites for turtles in the MHI

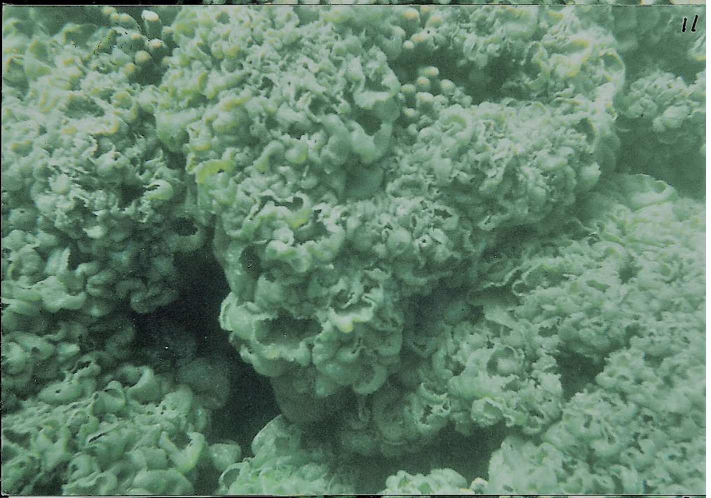
Important to consider the state of the algal community in the Bay because of speculation that turtles may have reached carrying capacity at some sites in the main Hawaiian Islands (Balazs and Chaloupka 2004)

This study is a very limited view of the Bay's algal community, does not consider algal resources on the barrier reef

Keep in mind the results on turtles I'm presenting are incidental to the principal observations I've been making, those on algal and herbivorous fish abundance in the bay

Up until 2006, *Dictyosphaeria cavernosa* was a widespread competitor with corals throughout the bay.
Its importance and increasing dominance was first appreciated in late 1960s.
Probably a native species

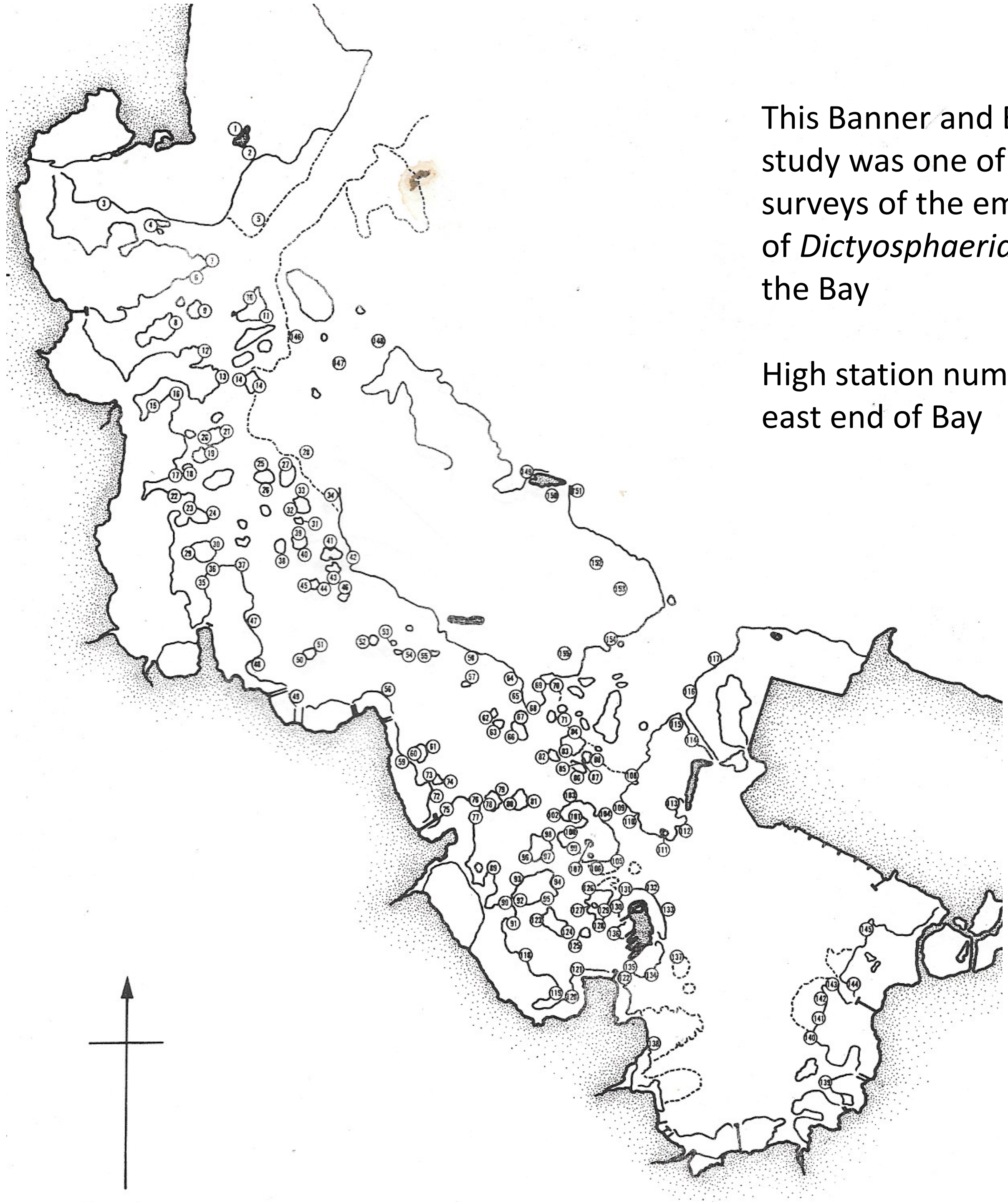
Morphology crispy and almost rigid



Ungrazed morphology

Grazed morphology

Among the first indications of the extent and coverage of this alga was a 1969 study



This Banner and Bailey 1969 study was one of the first two surveys of the emerging problem of *Dictyosphaeria* dominance in the Bay

High station numbers in south-east end of Bay

Coverage of *Dictyosphaeria* used to be high, and distribution in the Bay was broad: sewage discharge into the South Bay was implicated. Sewage input to the Bay was shut off in 1977, but by 1996/97 *Dictyosphaeria* was still abundant in the Bay

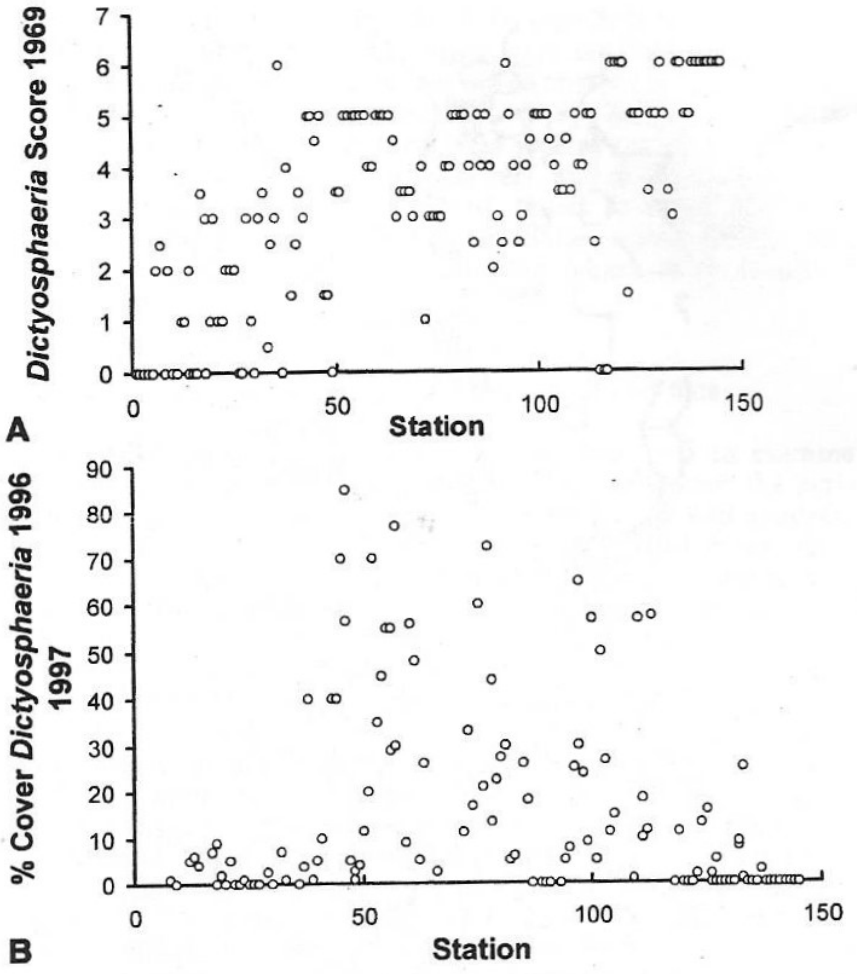
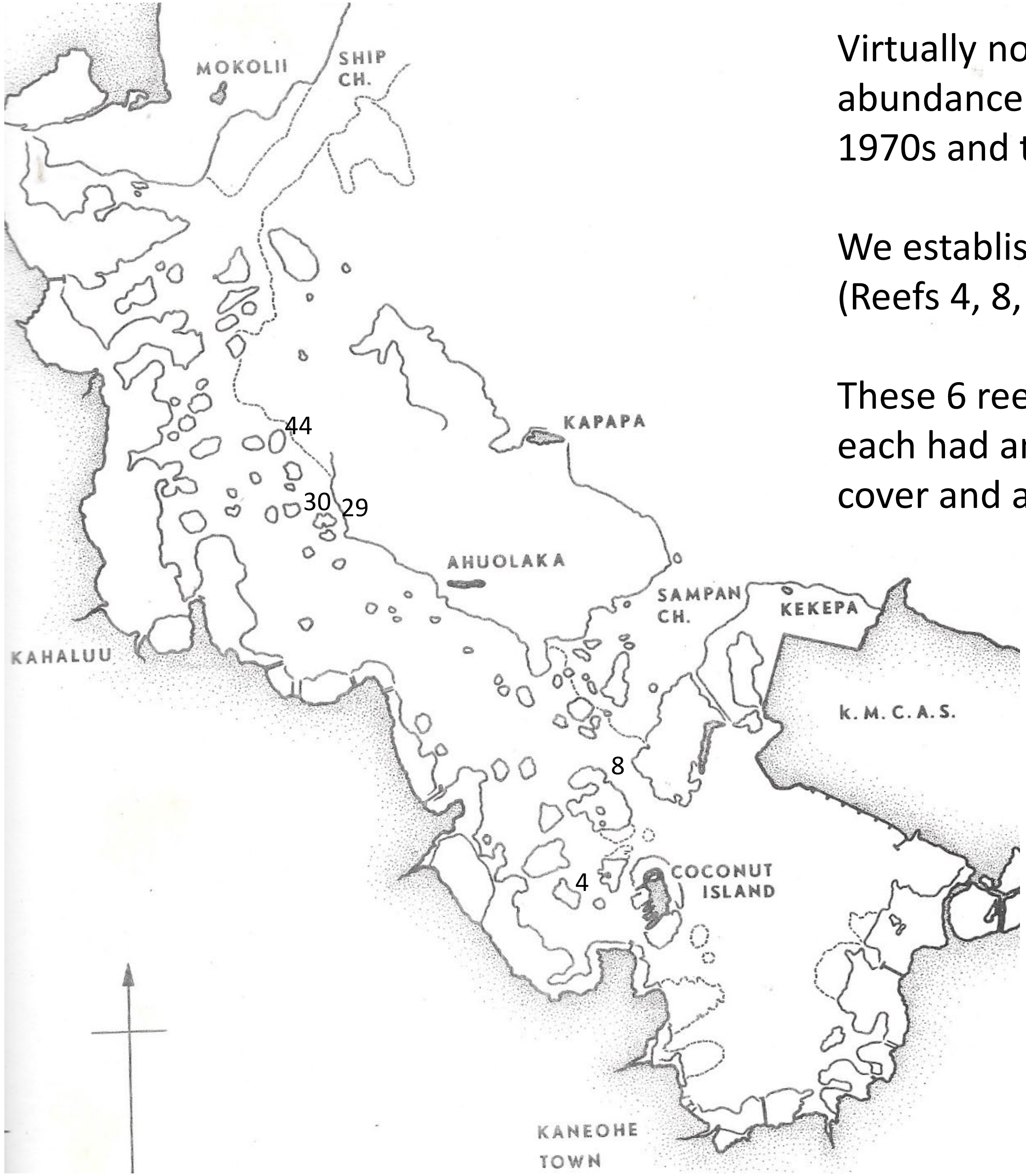


Fig. 3 Patterns of abundance of *Dictyosphaeria cavernosa* in Kaneohe Bay. **A** Pattern reported by Banner and Bailey (1970). Descriptions of conditions and associated scores are as follows: *0* no *D. cavernosa*, normal coral growth; *1* slight *D. cavernosa* growth, no interference with coral; *2* some invasion of coral heads by *D. cavernosa*; *3* heavy invasion of some or much of the coral, coral tips emergent (from *D. cavernosa* thalli); *4* most coral gone, remaining coral heavily invaded; *5* bottom either completely covered with alga or at most with only scattered heads of coral remaining; *6* neither living coral nor *D. cavernosa*, *D. cavernosa* replaced by mats of several other genera of algae. **B** Percent cover estimates made in 1996–1997 resurvey. Low-numbered sites are in north bay, high-numbered sites in south bay

1969 Prior to shut-off of sewage effluent into the Bay (Results of Banner and Bailey 1969 survey). High station numbers are in the SE end of the Bay. Scores above 3 are stations with high algal cover (see figure-text)

1996/97 Twenty years after the shut-off of sewage (1976/77)

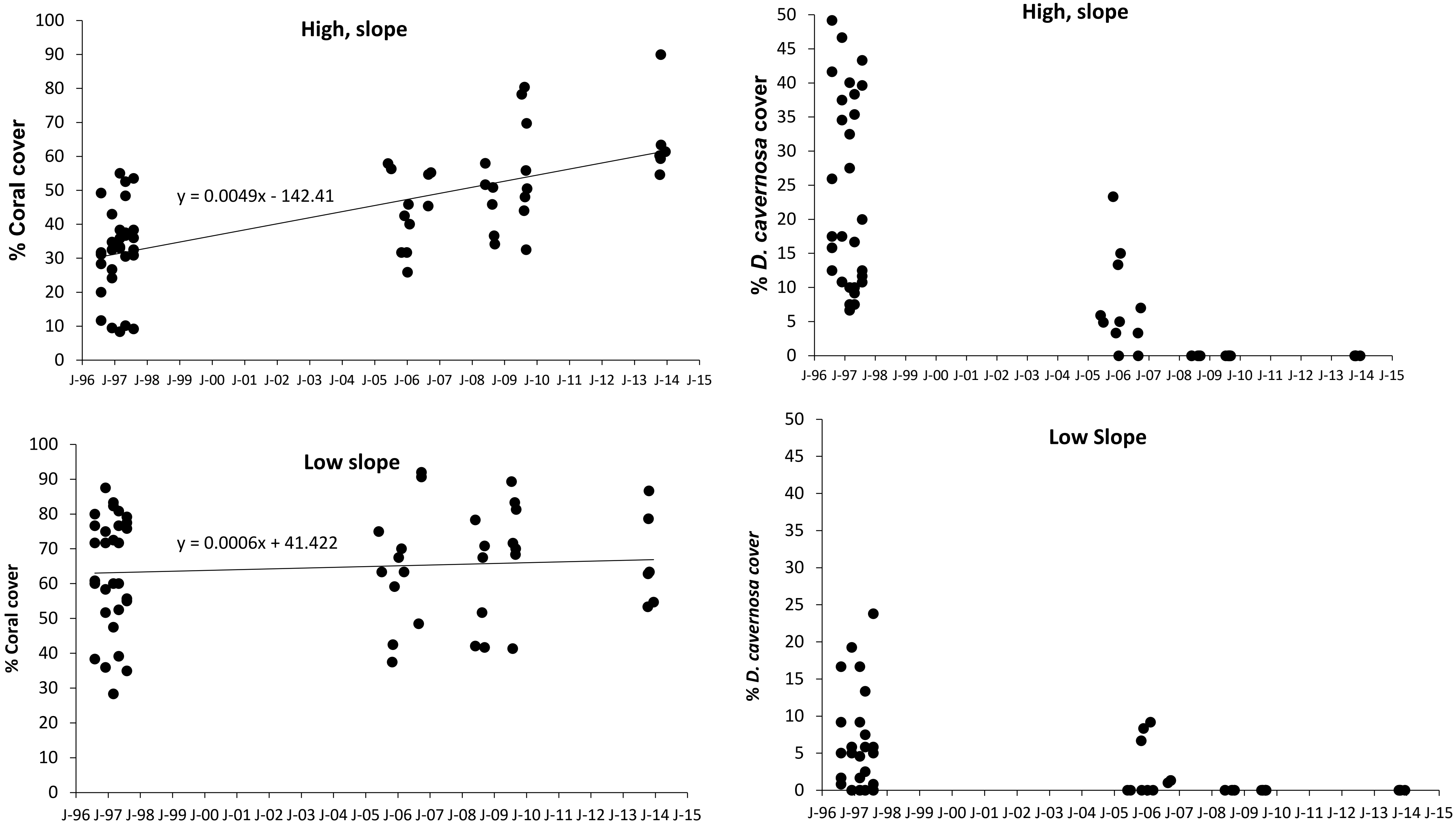


Virtually no data was collected on the abundance of *D. cavernosa* between the early 1970s and the 1990s.

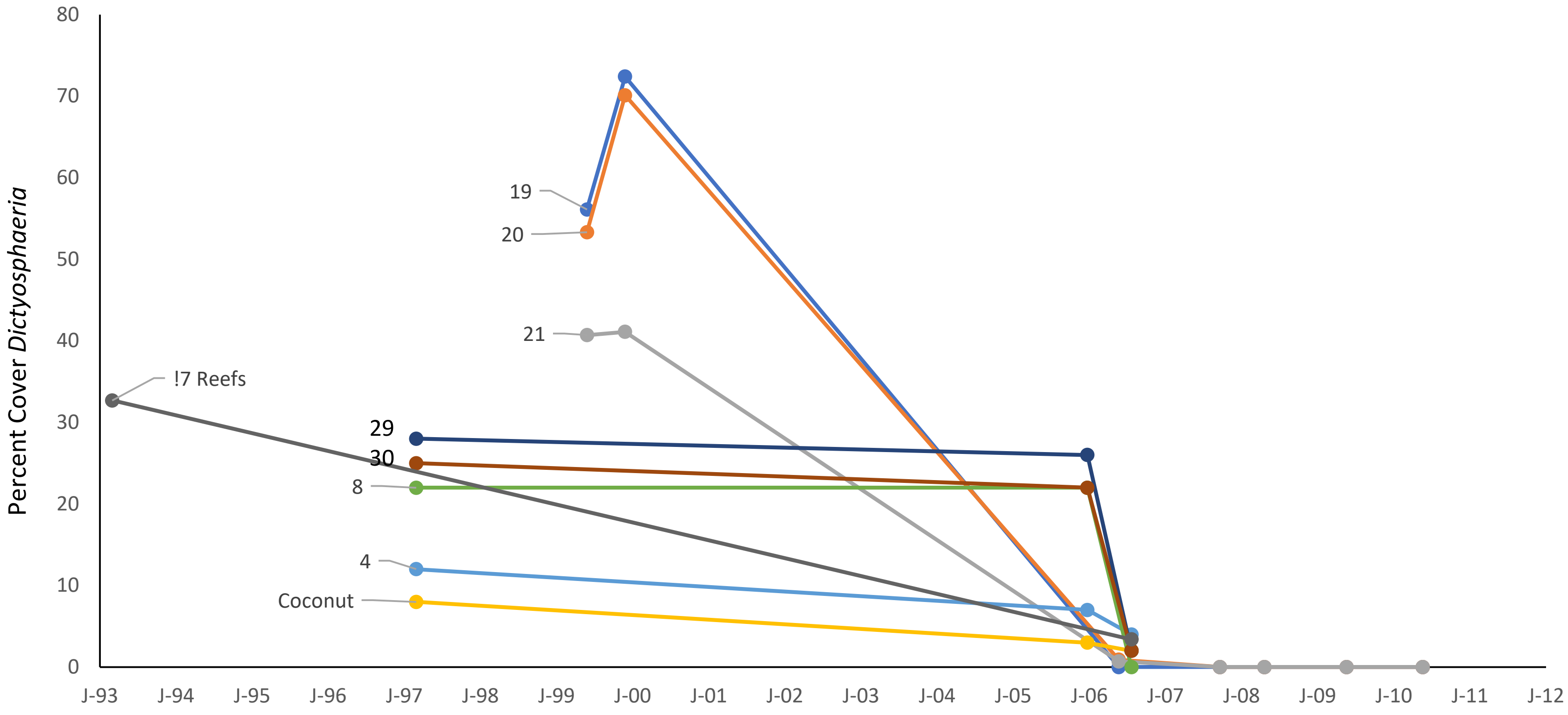
We established these 6 permanent sites in 1996 (Reefs 4, 8, 29, 30 44 and Coconut Island)

These 6 reefs were chosen for study because each had an area of **high** *D. cavernosa* cover and an area of **low** cover

Long–term decline in *D. cavernosa,* and recovery of coral cover on 6 reefs in permanent transects
(High and Low refer to *D. cavernosa* cover in 1996)
In 2006 virtually all *D. cavernosa* in the Bay disappeared



The suddenness of the 2006 decline in *D. cavernosa is* shown by records from some reefs



D. cavernosa still occurs in the Bay and grows in lab and field experiments, but its “dominance” has ended

Cause of decline of *Dictyosphaeria cavernosa*

40 days of rain and overcast in the period February to April of 2006

Overcast skies and turbid waters resulted in very low irradiance levels

February is also time of lowest water temperature

These spring months are a time of very slow growth in this particularly slow growing species (1% weight growth per day, compared to 15% for *Acanthophora)*

Subsequent lab experiments showed that thalli lost weight at temperatures and irradiance levels equivalent to those in spring of 2006

Grazing turtles and fish probably were not the cause of the decline, given its suddenness

Dictyosphaeria cavernosa is probably not a favorite of turtles

It was 19th in volume in turtle stomachs in a 2009 study based on pre 2005 data in the Bay despite relatively high cover of *D. cavernosa* on patch reefs at the time

It was lower than 10th in volume in a 2008 study based on 2003 data in the Bay

Can't really speak to dietary preferences of the turtles because we don't know the relative abundance of algal species in the Bay and how much time the turtles spent foraging in the different habitats which have distinctly different relative abundances of algal species

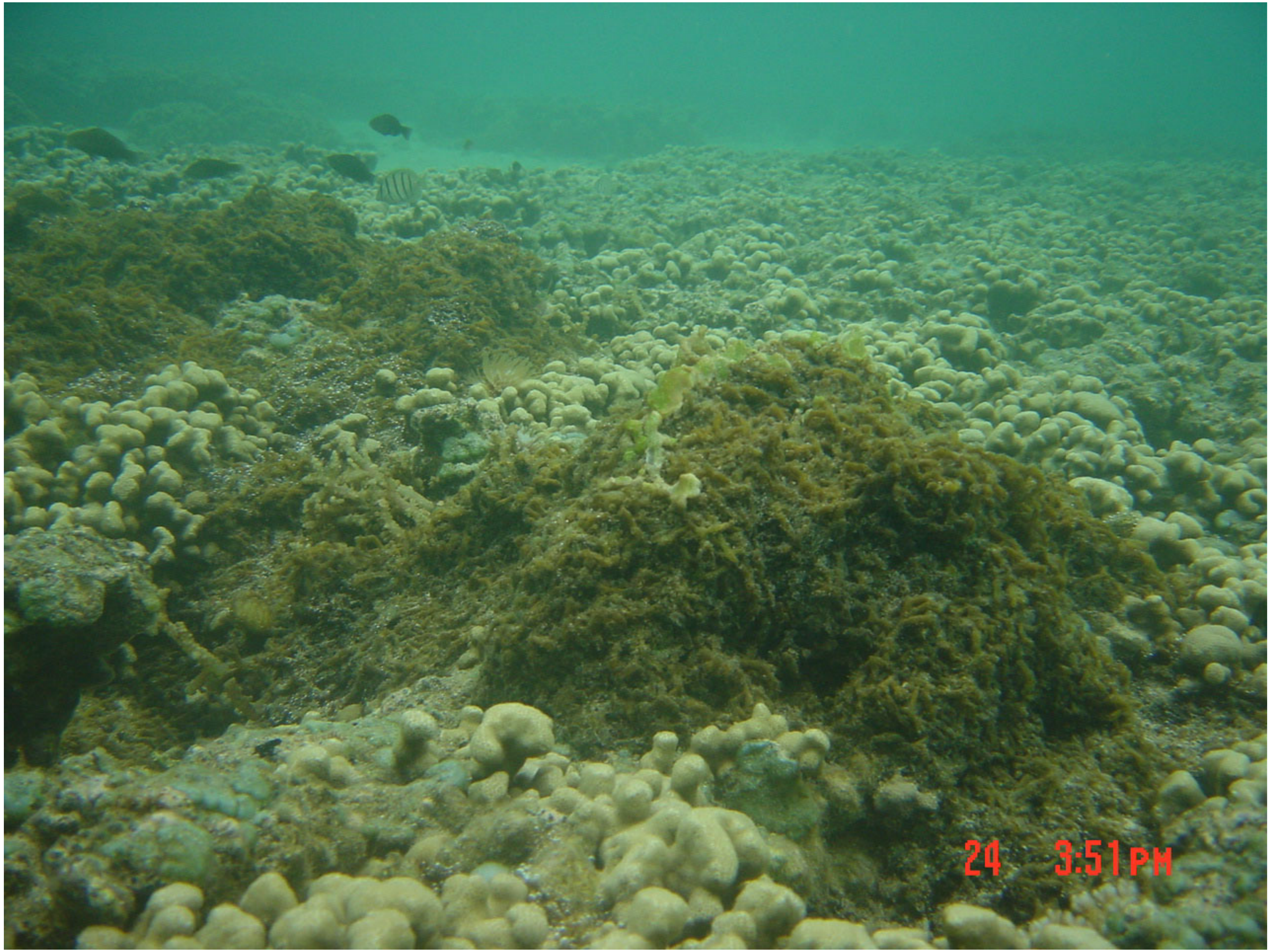
Second major algal decline in the Bay is that of *Gracilaria salicornia* and *Eucheuma denticulatum*

These alien algae were brought into the Bay in the 1970s

Not until the 1990s did people begin paying attention to their spread in the Bay

Gracilaria principally occupied reef flats, *Eucheuma* both reef flats and reef slopes

These are examples of well grazed thalli of *Gracilaria*



Inner section of the long abandoned HIMB sewer line, showing that the distribution of *G. salicornia* extends well onto the reef flat

Eucheuma denticulatum

On reef slope

on reef flat

Both in a very ungrazed state

Used these cages to examine the growth of *Eucheuma* and the intensity of grazing on it in 2 habitats on 8 different reefs in the Bay in summer and fall of 2014. (This picture happens to show *G. salicornia*)

Used change in wet weight over 2-day period to assess both growth and grazing

The weight losses of the uncaged thalli are evidently due to grazing by fish.

Reef flat algae had better growth (Inside cages) and less weight loss due to grazing (Outside cages) than reef slope algae

Comparison of specific growth (g g^{-1} d^{-1}) of caged and uncaged *E. denticulatum* thalli on reef flats and reef slopes (habitat) in Kāne‘ohe Bay. Values are means ± 1 SE; sample sizes in parentheses.

Average growth

	Inside cages	Outside cages
Reef flat	0.021±0.002 (19)	-0.013±0.006 (19)
Reef slope	0.010±0.001 (20)	-0.082±0.021 (20)

GLM Analysis

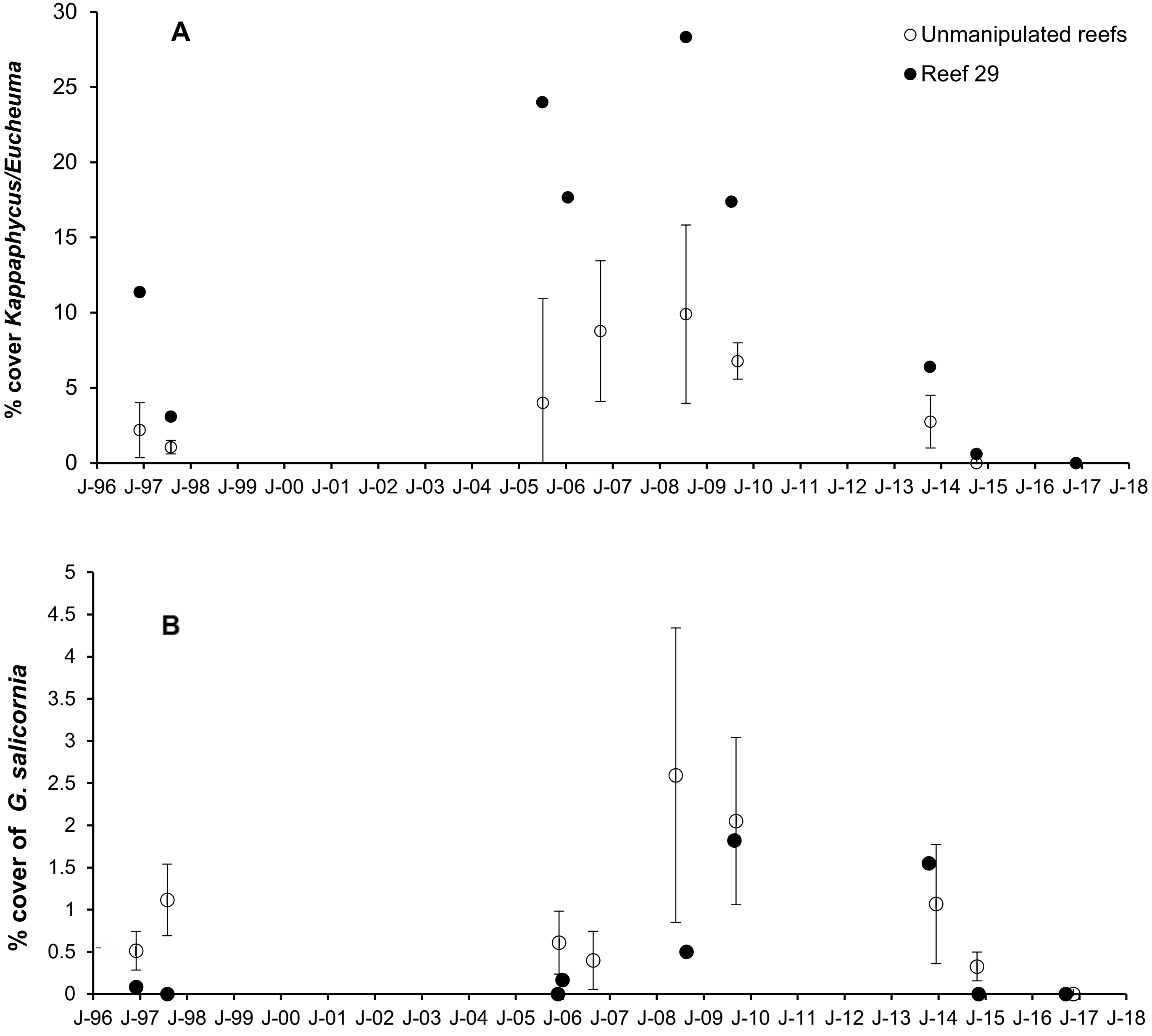
Source	df	MS	F	P
Caging	1	0.075	34.49	0.000
Habitat	1	0.028	12.76	<0.001
Blocks	1	0.027		
Habitat x Caging	1	0.016	7.18	0.009
Error	73	0.002		
Total	77			

The weight loss of *Eucheuma* due to grazing in previous table (in 2014) occurred during a period of declining cover of these two species

These records are from the six reefs originally chosen for the study of *Dictyosphaeria* cover

Reef 29 was used by others in studies of control methods in 2012, 2013,2014

The cover of these two alien red algae had declined by the time the growth/grazing experiments were performed in 2014, and continued to decline and stay low



Continued decline of *E. denticulatum* on a set of unmanipulated reefs in Kaneohe Bay

Comparison of the percentage cover of *Eucheuma denticulatum* on unmanipulated reefs in 2014 with that in 2018.

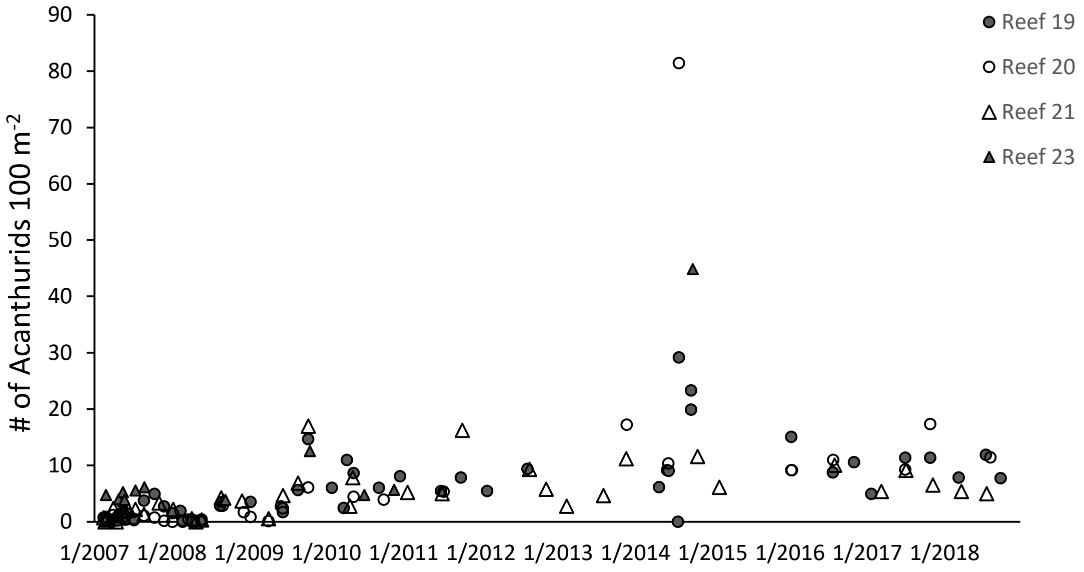
	2014	2018
Average cover	9.20	1.56
Range	0-27.4	0-6
Number of reefs	8	8

Cover is different between years by a Wilcoxon's Signed Rank test $P < 0.01$

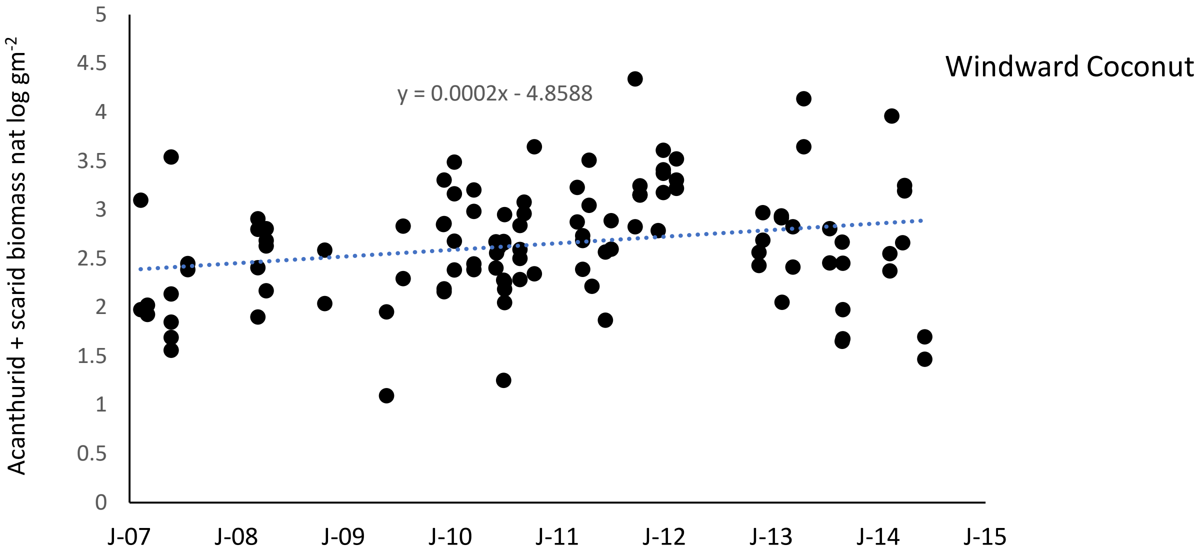
Surveys of the abundance of herbivorous reef fishes have been conducted on a set of 4 small patch reefs in the central bay, and on the windward fringing reef of Coconut Island

The number of herbivorous fish are counted in 50 to ~100 m long transects which extend along the reef crest, 3 m onto the reef flat and 5 m down the reef slope

Prior to the 2008 to 2014 decline in the cover of these red algae, there was a period of increase in grazing fish biomass. The data in the top graph shows a significant increase in the numbers of herbivorous fishes (2014 spike excluded from analysis); the data in the bottom graph shows a significant increase in the biomass of herbivorous fishes.



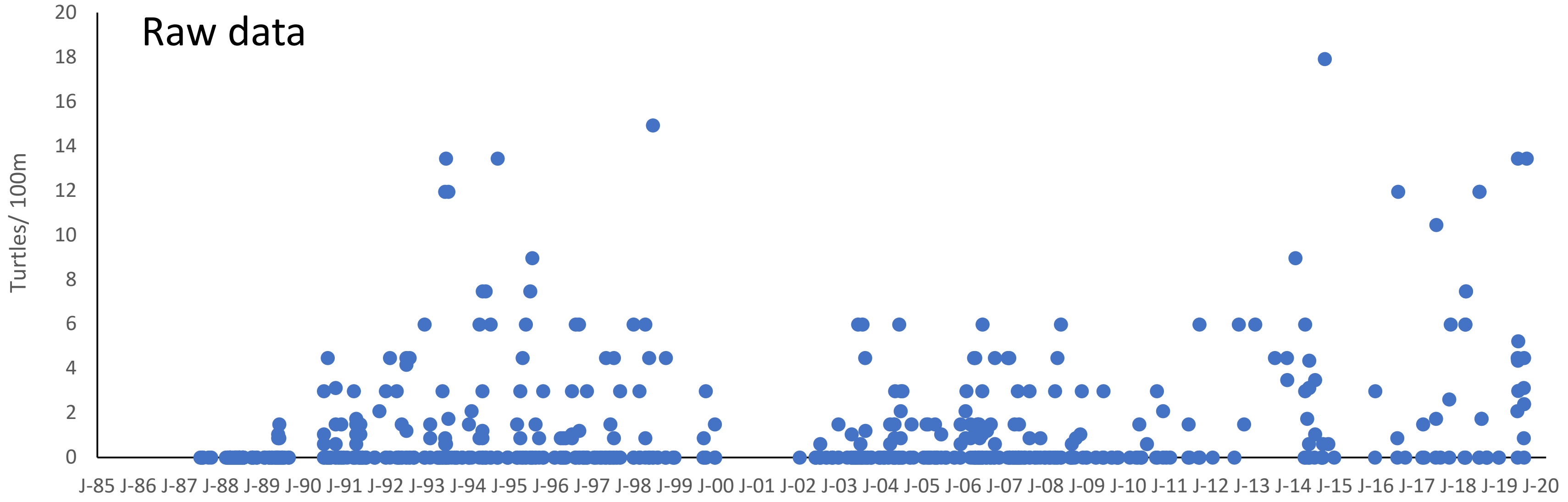
This is an increase from 19 g m^{-2} to 33 g m^{-2}



Some incidental censuses of turtles were made on these 5 reefs while censusing herbivorous reef fishes

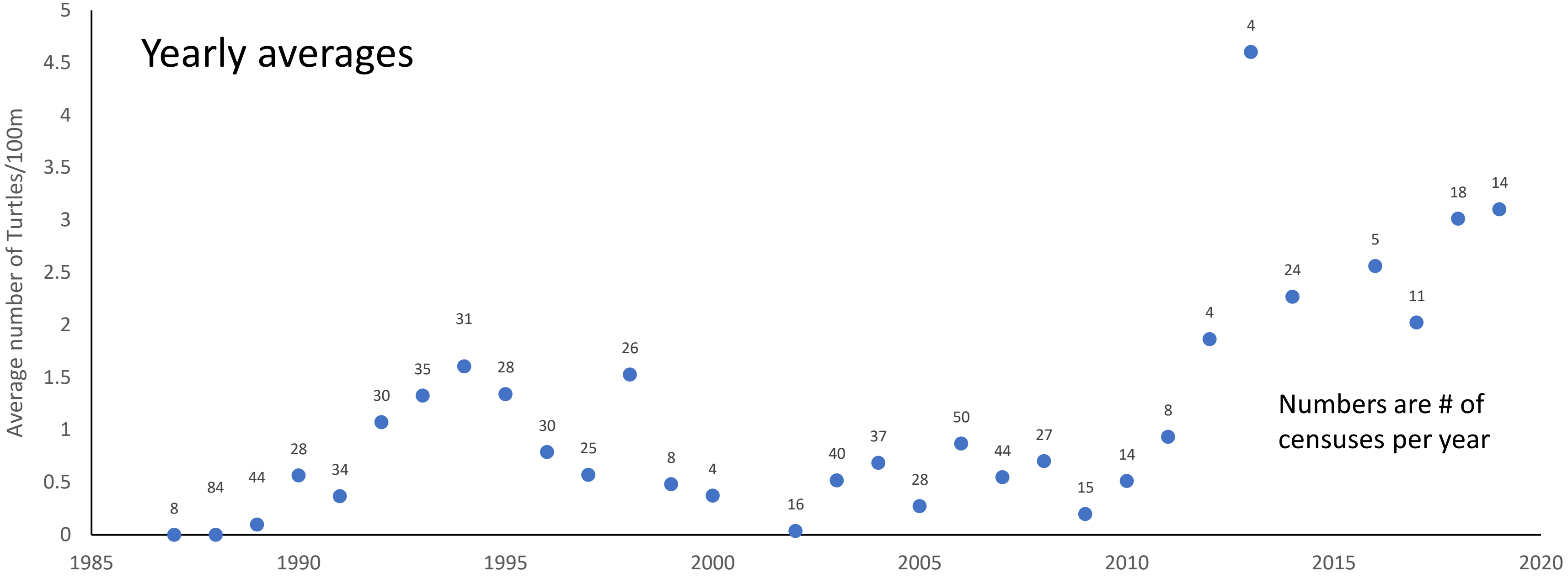
Lots of zeroes, but this top graph is number of turtles per 100 m of reef perimeter on 4 small central-bay patch reefs, and it suggests an increase in turtle numbers

Bottom graph expresses same data as yearly averages

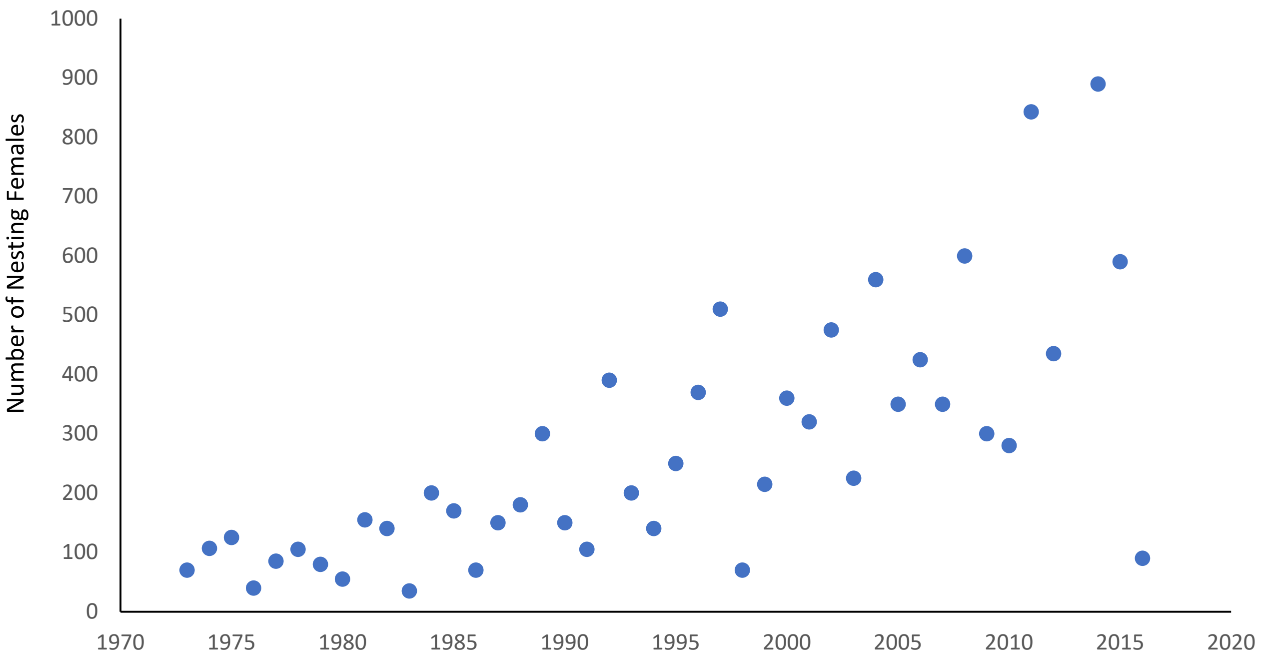


There were as many as 150 (1991) captured and tagged in a year between 1989 and 1997 (Balazs et al 1998)

Losey et al published a paper in 1994 describing a never-before-seen phenomenon of turtles being cleaned by saddle wrasses in Kaneohe Bay

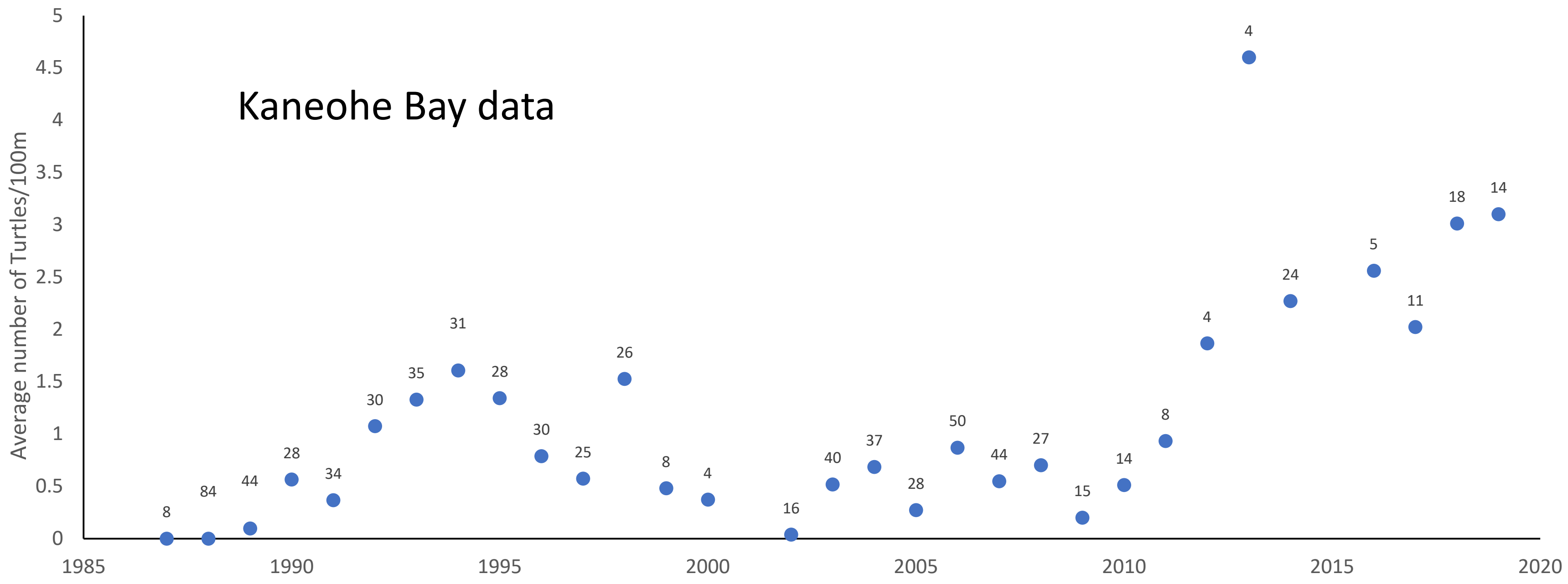


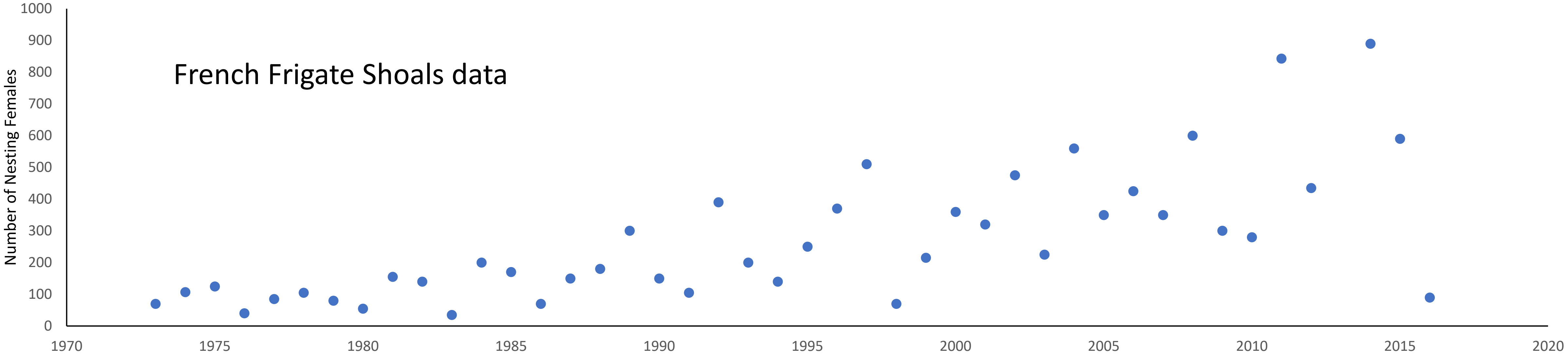
French Frigate Shoals record of nesting green turtle abundance



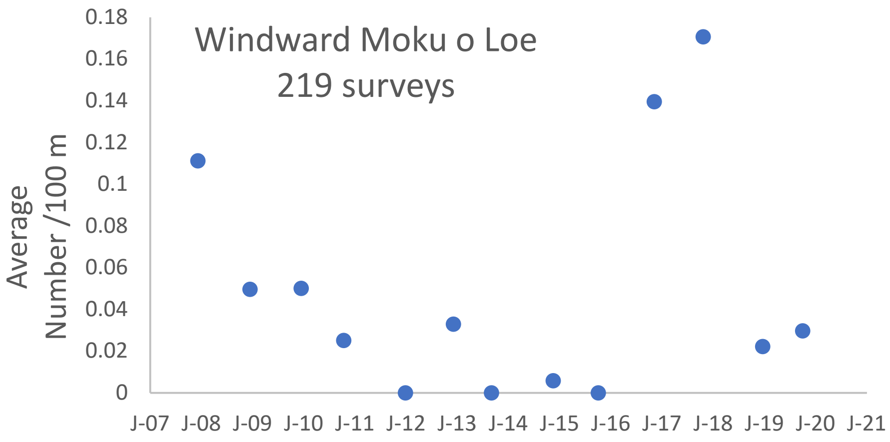
Comparing the trend in the FFS census results with the trend in Kaneohe Bay

So, increase in numbers in the Bay is part of a general increase in abundance in Hawaii as measured at FFS



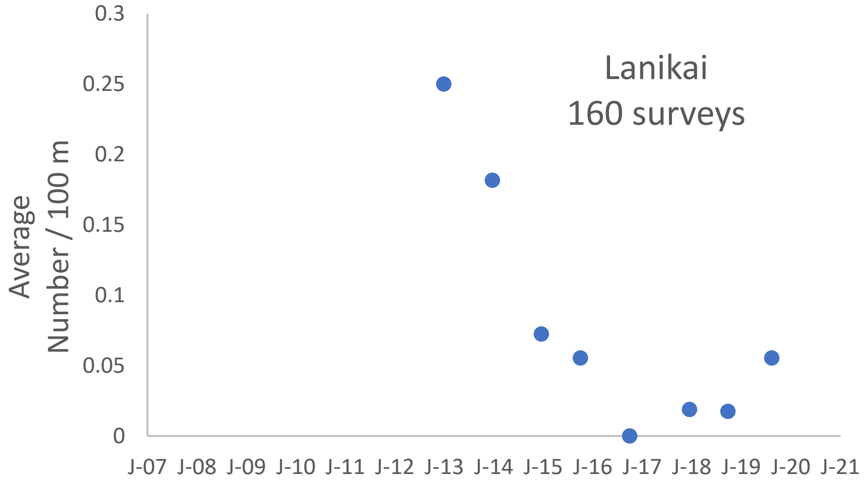


But not all sites evidently show the same pattern of abundance as that recorded on Reefs 19, 20, 21, and 23



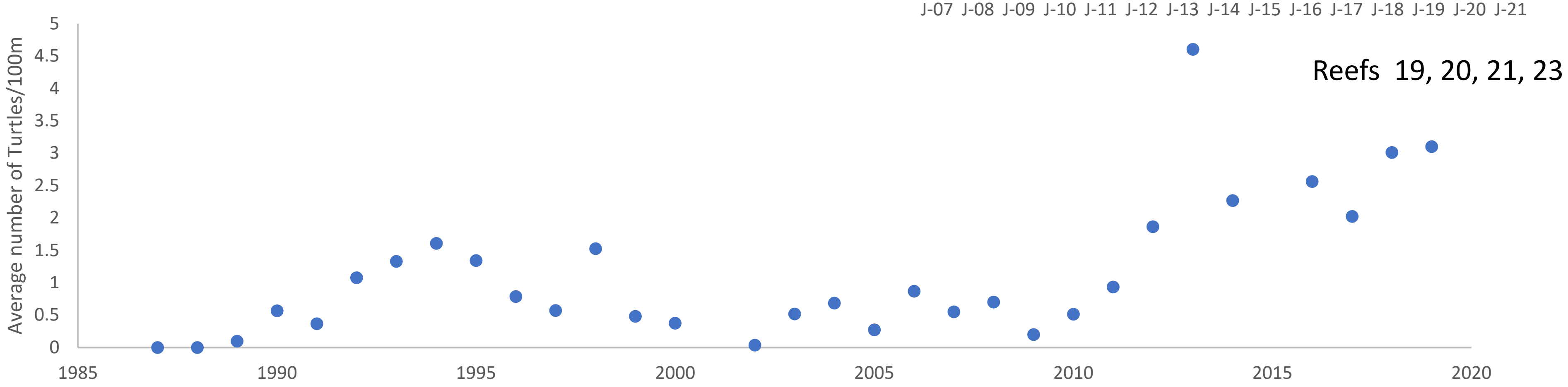
High numbers at Moku o Loe in 2017/18 corresponded with the observations of turtles eating *Gracilaria* in lagoonal sites at HIMB

Recent low numbers at Lanikai



Suggestion is that turtles are tracking the abundance of macroalgae and adjusting densities accordingly

Note that vertical scales are different



Conclusion

The combination of herbivory by reef fishes and turtles probably has brought about the decline of introduced red algae in Kaneohe Bay

Fishes

They caused weight loss of *E. denticulatum* in the caging experiment on both the reef flat and reef slope at the same time the cover of the two reds was declining

The density and biomass of herbivorous reef fishes at two sites in the Bay has shown a long term increase

Have watched yellow tang and sail-fin tang eating the uncaged *Eucheuma* on experimental platforms

Turtles probably also played a role in the decline in cover of these introduced and invasive algae

Inclusion of introduced red algae in turtle diets (Russell and Balazs 2009)

The decline in *Gracilaria* abundance at Coconut Island in association with turtle abundance (Bahr et al 2018)

The increasing abundance of turtles in the Bay

I'm hoping there will be the institution of long-term study of turtle abundance and algal resource abundance in the Bay given the importance of importance of turtles in controlling alien invasive algae in the Bay, and the question of whether turtles are approaching carrying capacity at sites in Hawaiʻi

Acknowledgements

Eric Conklin, Joyce Fender, Al Hart, Scott Larned
Contributed to the field work on algae and turtles

My thanks to HIMB for use of the sea water system and for serving as a base for operating in Kaneohe Bay, and to the Dept. of Biology for access to their boat

Gracilaria salicornia in its present day refuge close to shore