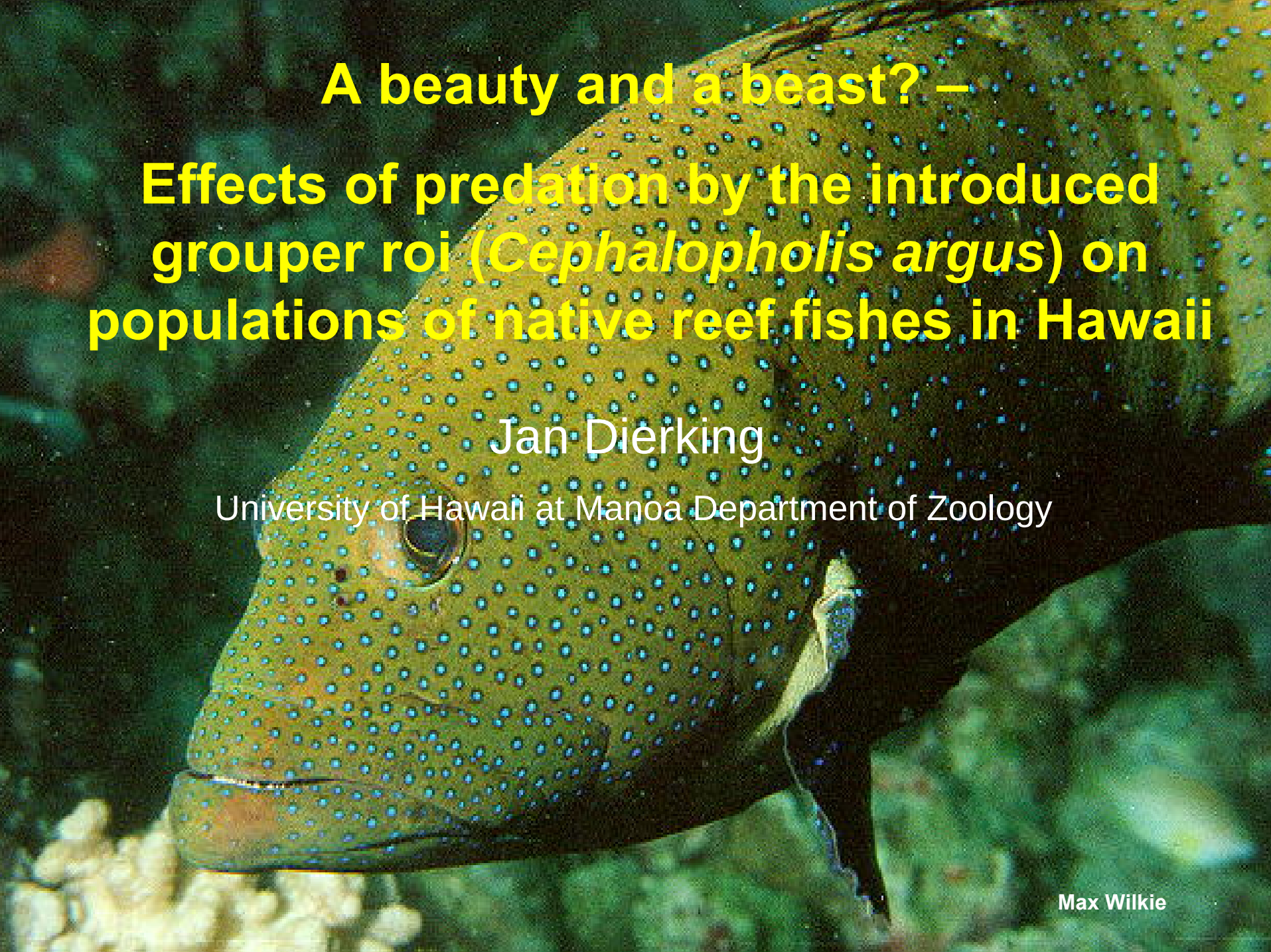
# A beauty and a beast? – Effects of predation by the introduced grouper roi (*Cephalopholis argus*) on populations of native reef fishes in Hawaii

Jan Dierking

University of Hawaii at Manoa Department of Zoology



Max Wilkie

# Outline

## Effects of predation by the introduced grouper roi (*Cephalopholis argus*) on populations of native reef fishes in Hawaii

- Background
- Ciguatera in ro
- Feeding biolog

(Effects of ciguatera on roi fit

Photo: Bill Walsh

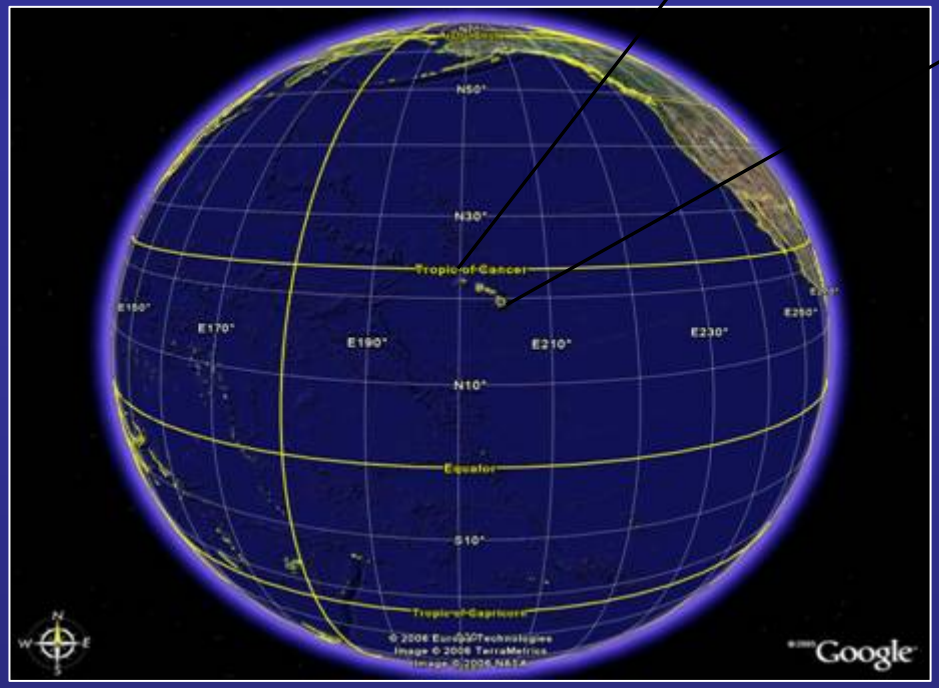
# Hawaii

## Isolation:

→ few species immigrate successfully

→ strong natural selection pressure; evolution of new species

(Gosline 1968)



# Hawaii

## Isolation:

→ few species immigrate successfully

→ strong natural selection pressure; evolution of new species

## Nearshore marine fish communities

→ 24.3% rate of endemism → highest in the world

→ Limited presence of many families of marine fishes common elsewhere in the Pacific, including the grouper family (Serranidae).

# Roi

Peacock grouper *Cephalopholis argus*

- Family Serranidae, subfamily Epinephelinae (Groupers)

# Roi

## Peacock grouper *Cephalopholis argus*

- Family Serranidae, subfamily Epinephelinae (Groupers)
  - 159 species
  - most important predators of the coral reef system
  - slow growth, late reproduction, long life-span, low metabolic rate
  - valuable food fish
  - overfished (~50% of grouper species threatened)

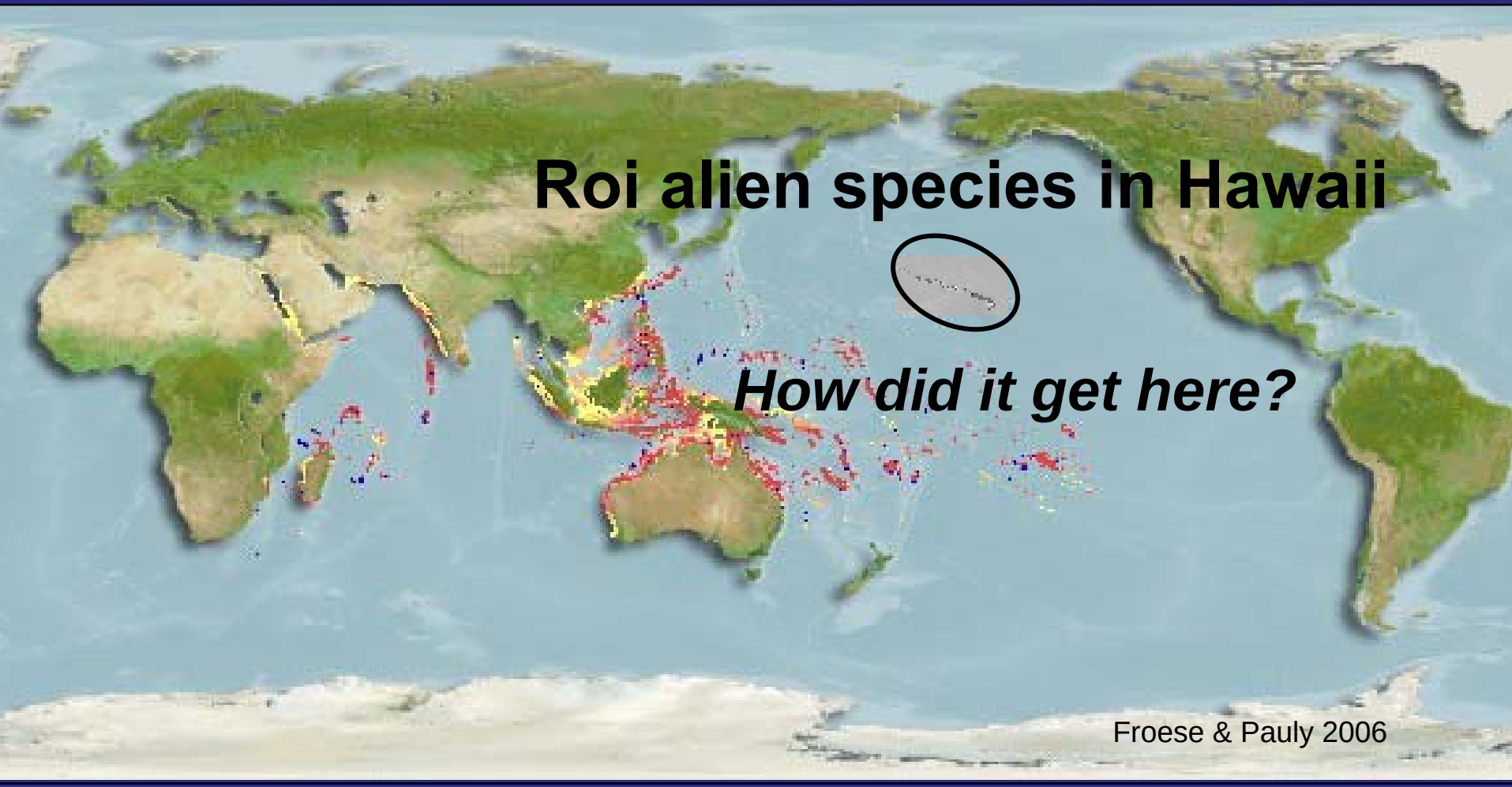
Heemstra & Randall 1993

# Roi

Peacock grouper *Cephalopholis argus*

- Family Serranidae, subfamily Epinephelinae (Groupers)
- Predatory reef fish
- Valuable in many locations, e.g., Guam, Palau, Hong Kong
- In decline in some locations

# Distribution



# Back to the 1950s

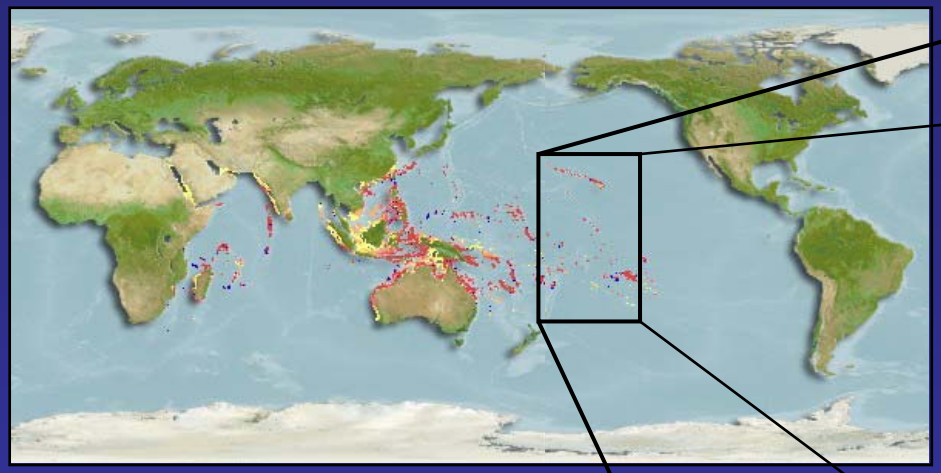
## Hawaii Division of Fish & Game

- Noted in its 1956 Annual report:

"…*fishes in the shallow inshore areas in Hawaii are on a declining trend*…".

- Proposed to introduce fish species valued as food or game fishes elsewhere to Hawaii to enhance fisheries

→ Species introduction program: Groupers & Snappers



# Introduction of roi

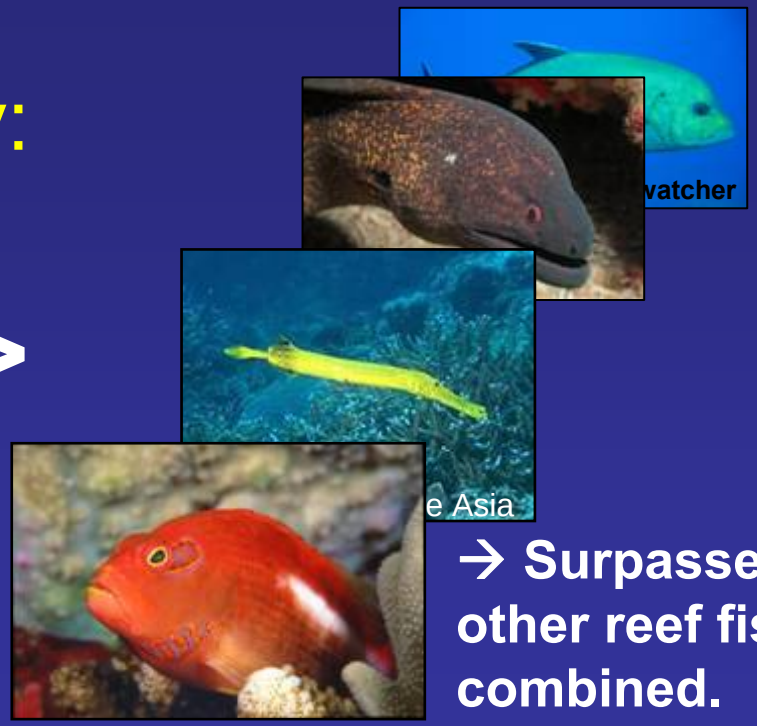
→ Juveniles sighted by the mid 1960s.

→ roi rare till the 1980s

→ 15-fold increase since then

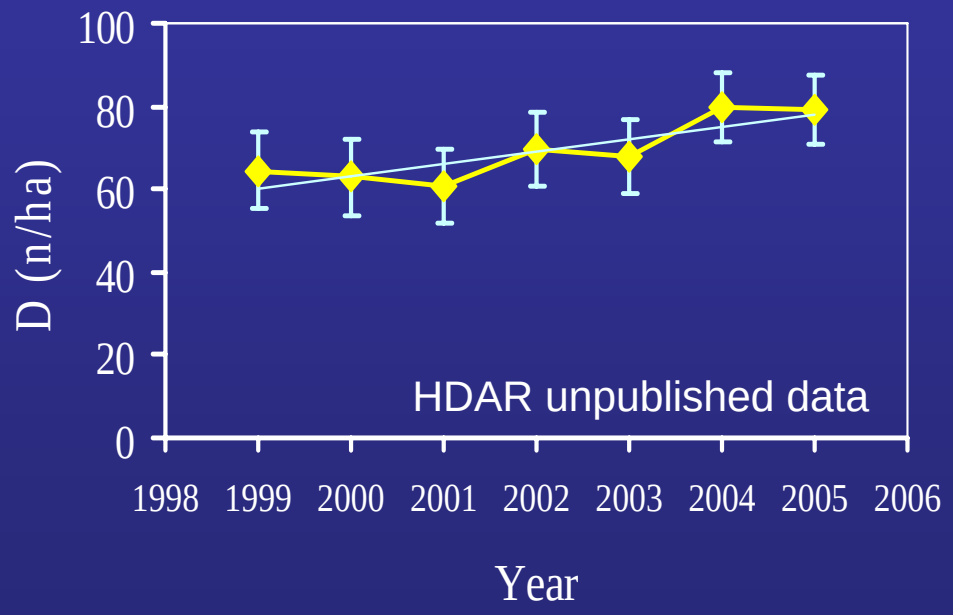
# Situation today:

>




→ **Surpasses biomass of all other reef fish predators combined.**

- **23% increase 1999 - 2005**

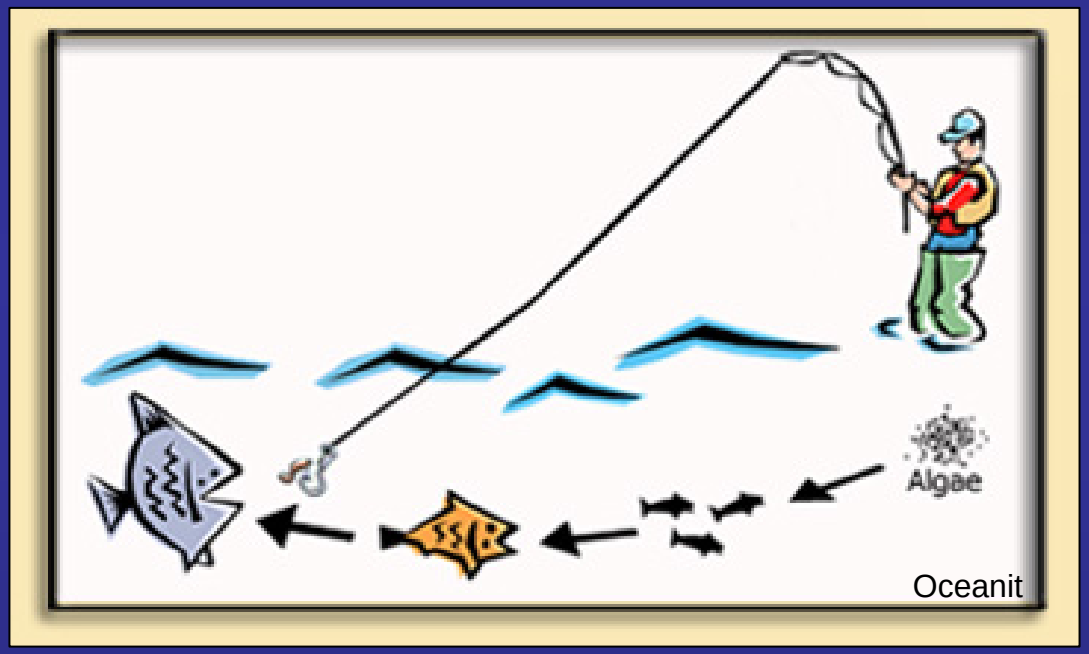


## Situation today:

*Abundant roi, functional roi fishery?*

# The ciguatera problem

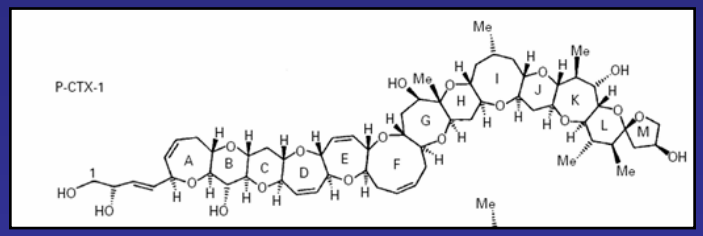
Ciguatera fish poisoning: “neurological disease in humans resulting from the ingestion of ciguatoxic fish” (Hokama & Ebesu 2001)

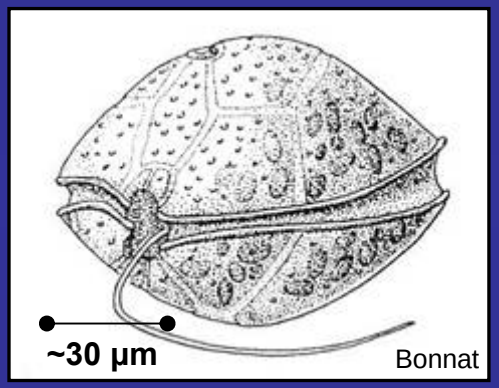



Carnivores ← Herbivore ← (Ciguatoxin ← Dinoflagellate)

# The ciguatera problem

- Food chain concept of ciguatera (Randall 1958)
  - Ciguatoxin isolated in 1967 (Scheuer et al.)
  - *Gambierdiscus toxicus* (Yasumoto et al. 1980)
    - ~ 50,000 cases per year
  - Public health & economic factor:



# Roi in Hawaii and Ciguatera

Fishes associated with ciguatera fish poisoning in Hawai'i (1996-2000):

| Common Name | Incidents |
|---|---|
| Roi | 20 |
| Jack | 20 |
| Surgeonfish (var.) | 18 |
| Surgeonfish (Kole) | 16 |
| Goatfish | 10 |
| Snapper | 9 |
| Barracuda | 4 |
| Moray Eel | 4 |
| Mullet | 4 |
| Other | 20 |
| Total | 126 |

(DOH Communicable Disease Report 2001)

→ Bad reputation

→ Rarely caught by commercial and recreational fishermen

→ Annual sales of roi average: ~ $1,000/year

(DAR Commercial Marine Landings reports)

**→ No functional fishery!**

# The perception of the people

Hawaii Skindiver Magazine

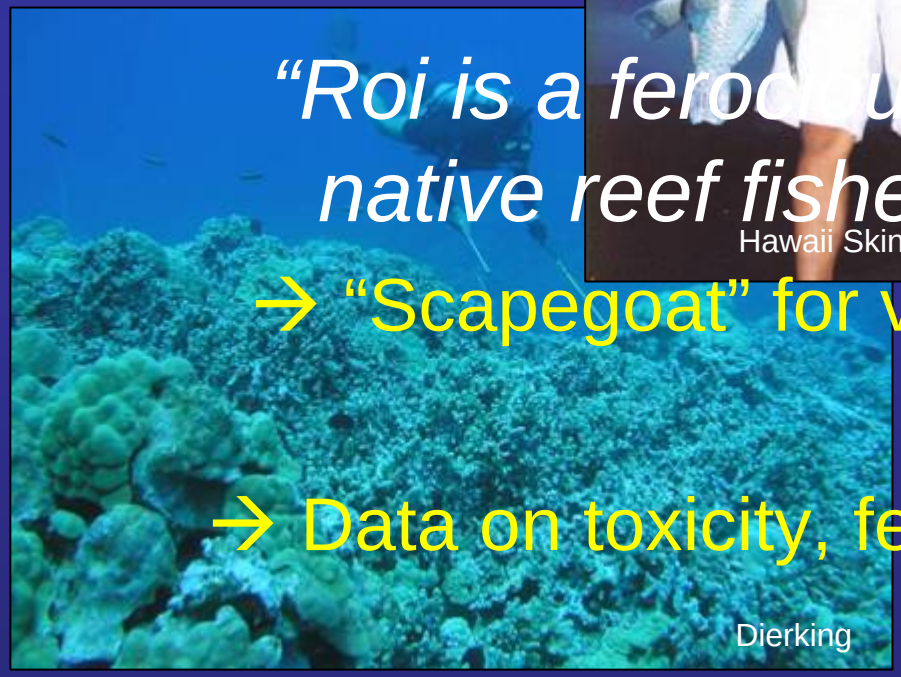
*"Don't eat roi, it's ciguatoxic!"*

→ Prevents fishery for roi

Kona coast divers

*"Roi is a ferocious predator & harms native reef fishes!"*

→ "Scapegoat" for various problems


Dierking

→ Data on toxicity, feeding, not available

# My Project

## 1. Ciguatera

- *Is roi as toxic as perceived by reef users?*
- *Are there predictable patterns in toxicity?*

## 2. Feeding biology

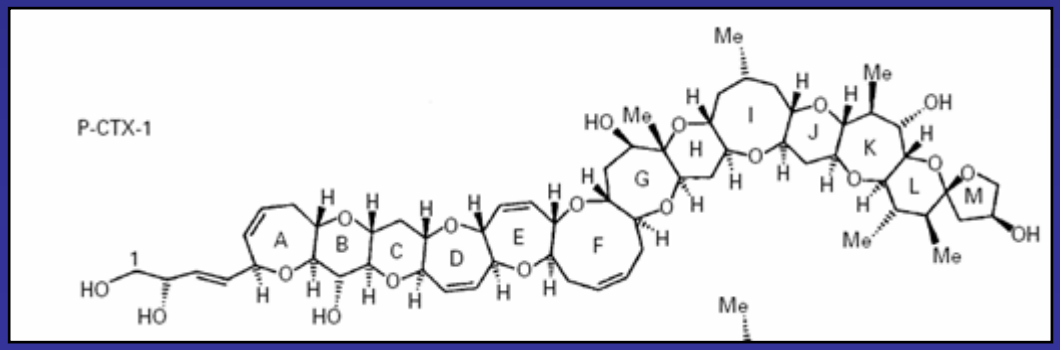
- *What does roi feed on in Hawaii?*
- *How much prey is consumed by roi populations in Hawaii?*

**Secondary**

- Feasibility of a roi fishery
- Roi impact on native species

***Roi - A beauty and a beast?!***

# Ciguatera



# Ciguatera

1. ***Is roi as toxic as perceived by reef users?***

2. ***Are there predictable patterns in toxicity?***

   a. Geographic patterns

   b. Correlation of roi size & toxicity

---

- Republic of Kiribati: Fish on certain reefs are commonly ciguatoxic, fish from all other reefs are predictably safe (Lewis 1992)

**vs.**

- Barracuda in Florida: high prevalence of toxic fish at all analyzed sites (De Sylva 1994)

# Ciguatera

1. ***Is roi as toxic as perceived by reef users?***

2. ***Are there predictable patterns in toxicity?***

   a. Geographic patterns

   b. Correlation of roi size & toxicity

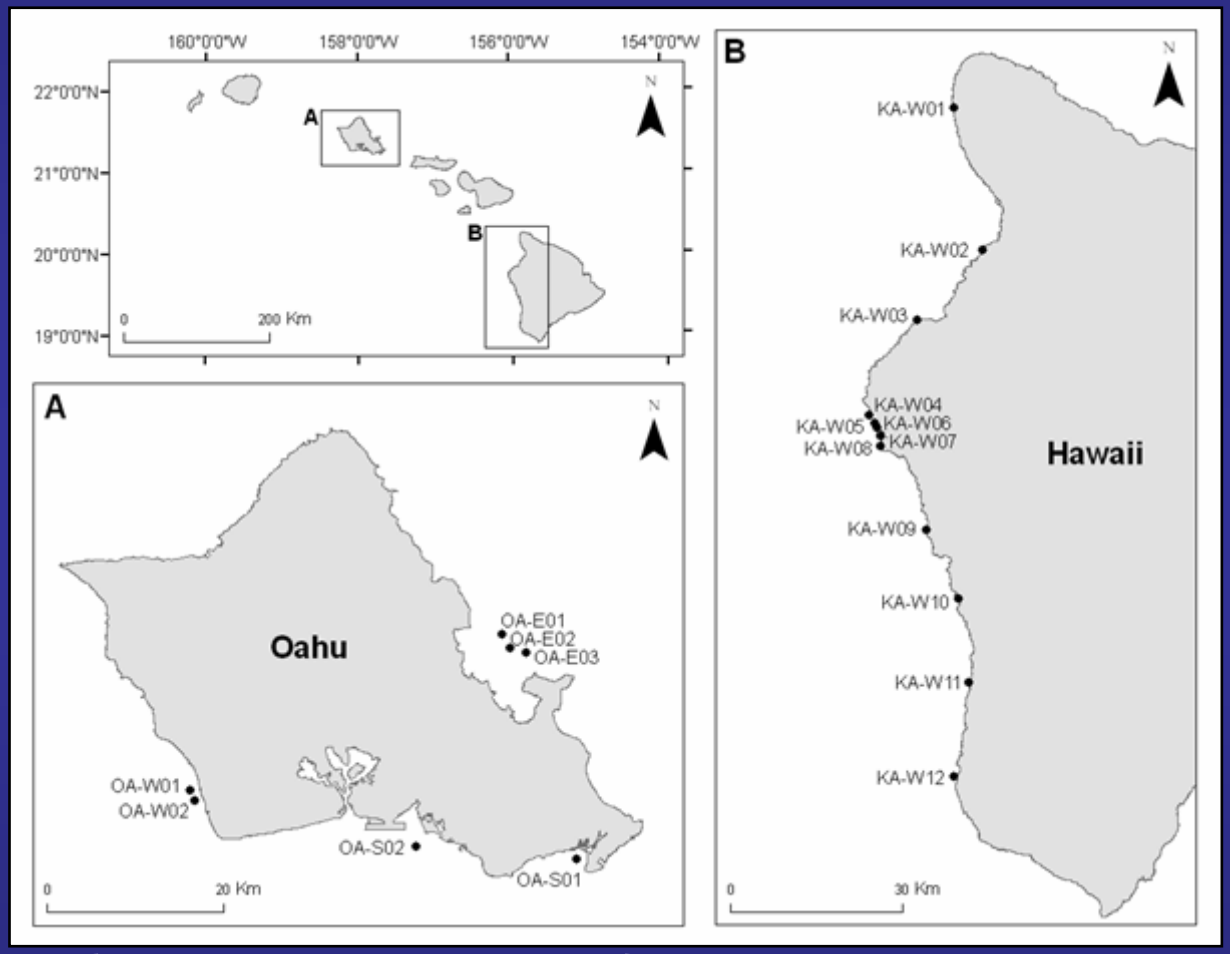
---

- Bioaccumulation hypothesis → older, larger fish increase in toxicity

(Lehane 1999)

# Sampling

Spearfishing, July/Aug. 2003, with a team of 5 divers




**11 sites**
**186 roi**

**6 sites**
**106 roi**

# Method

## Hokama's (1998) Monoclonal Immunobead Assay (MIA)

- Semi-quantitative assay of ciguatoxin concentration
- Only commercially available test at this time.
- Used by Hawaii DOH to test fish suspected in ciguatera outbreaks.

## MIA test scores

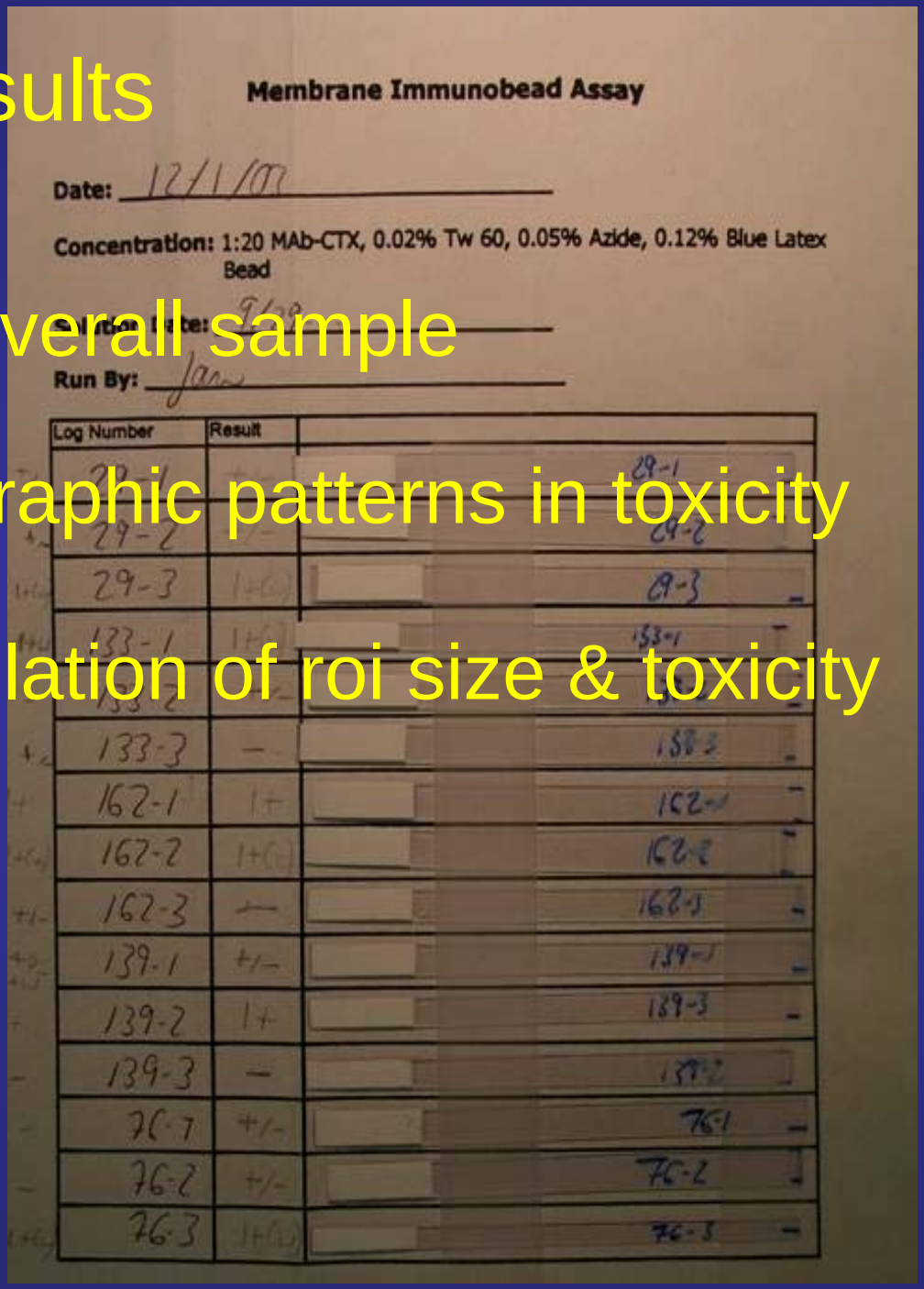
- Toxicity of a fish expressed as score between 0 & 6 (steps of 0.5) (based on assays run on muscle tissue samples from head, body and tail)

## Interpretation

| Fish score range | Score class | Interpretation |
|---|---|---|
| < 0.5 | Negative | **Safe** |
| 0.51 – 2 | Marginal | **Safe** |
| 2.01 – 4 | Positive | **Unsafe** (Incident possible) |
| > 4 - 6 | Strong positive | **Unsafe** (Incident likely) |

# Results

- The overall sample
- Geographic patterns in toxicity
- Correlation of roi size & toxicity



**Membrane Immunobead Assay**

**Date:** 12/1/07

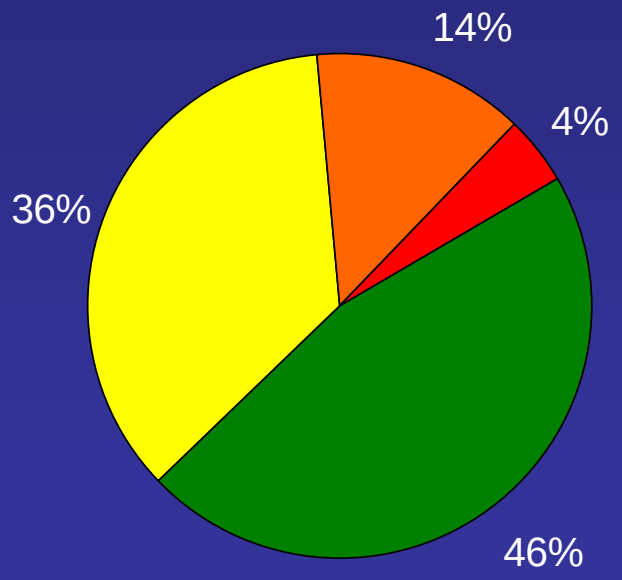
**Concentration:** 1:20 MAb-CTX, 0.02% Tw 60, 0.05% Azide, 0.12% Blue Latex Bead

**Run By:** Jan

| Log Number | Result | |
|---|---|---|
| 29-1 | + | 29-1 |
| 29-2 | + | 29-2 |
| 29-3 | 1+(-) | 29-3 – |
| 133-1 | 1+(-) | 133-1 – |
| 133-2 | + | 133-2 – |
| 133-3 | – | 133-3 – |
| 162-1 | 1+ | 162-1 – |
| 162-2 | 1+(-) | 162-2 – |
| 162-3 | – | 162-3 – |
| 139-1 | +/– | 139-1 – |
| 139-2 | 1+ | 139-3 – |
| 139-3 | – | 139-2 – |
| 76-1 | +/– | 76-1 – |
| 76-2 | +/– | 76-2 – |
| 76-3 | 1+(-) | 76-3 – |

# The overall sample

+




- Negative
- Marginal
- Positive
- Strong positive

→18% of roi unsafe for consumption

n = 292

## Perspective: Ciguatoxicity in other reef fishes

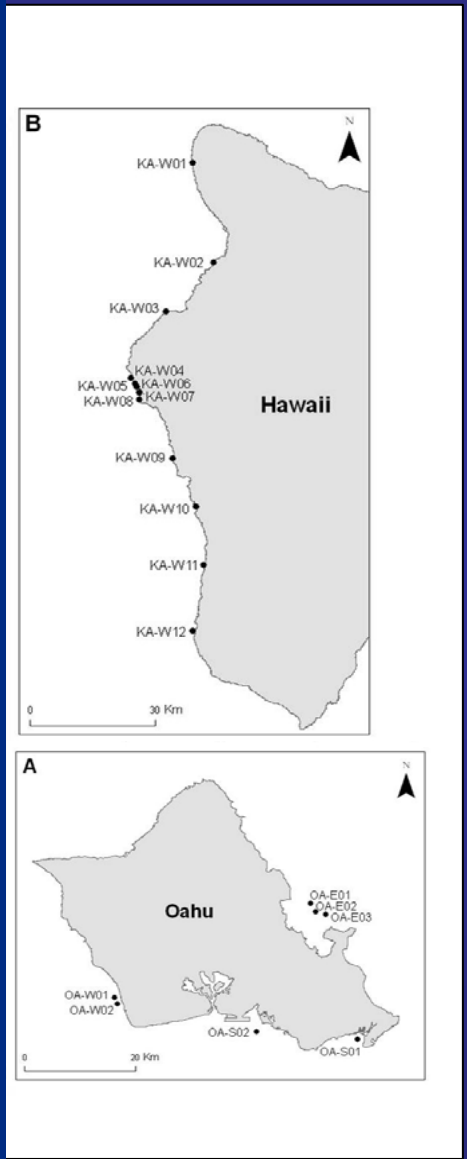
| Group/species | Frequency | Source |
|---|---|---|
| HI reef fishes overall | 4% | Hokama et al. 1998 |
| Amberjack, Hawaii | 15% | Kimura et al. 1982 |
| Great barracuda, Florida | 30% | Bottein Dechraoui et al. 2005 |

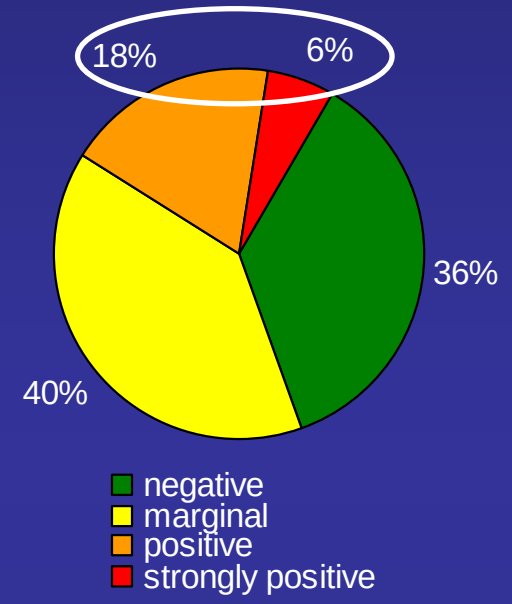
# Geographic patterns in ciguatoxicity

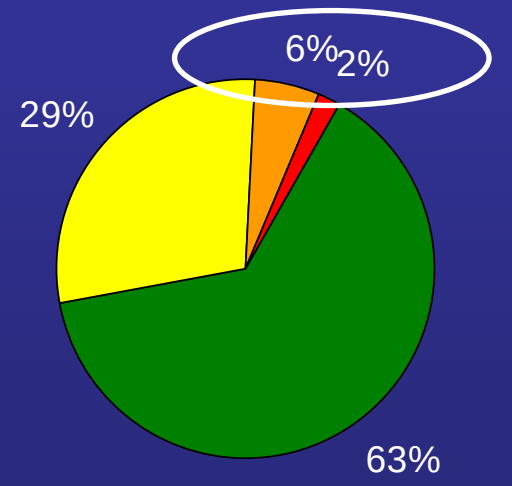
# Geographic patterns – Island level

| Origin | Mean score |
|---|---|
| Kona | 1.55 |
| Oahu | 0.73 |

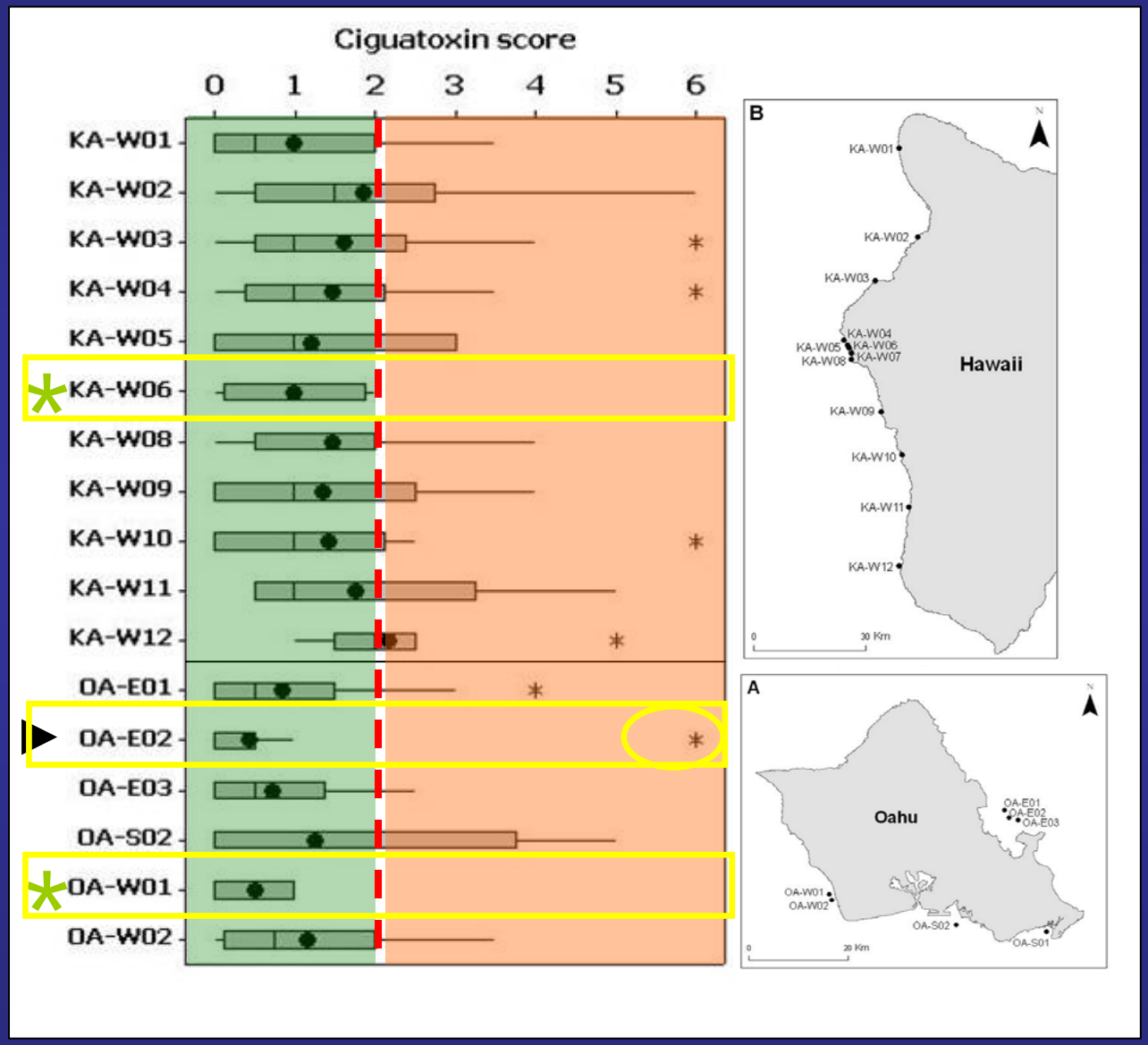
Difference significant
(t test using site means as sampling units, $p<0.001$)



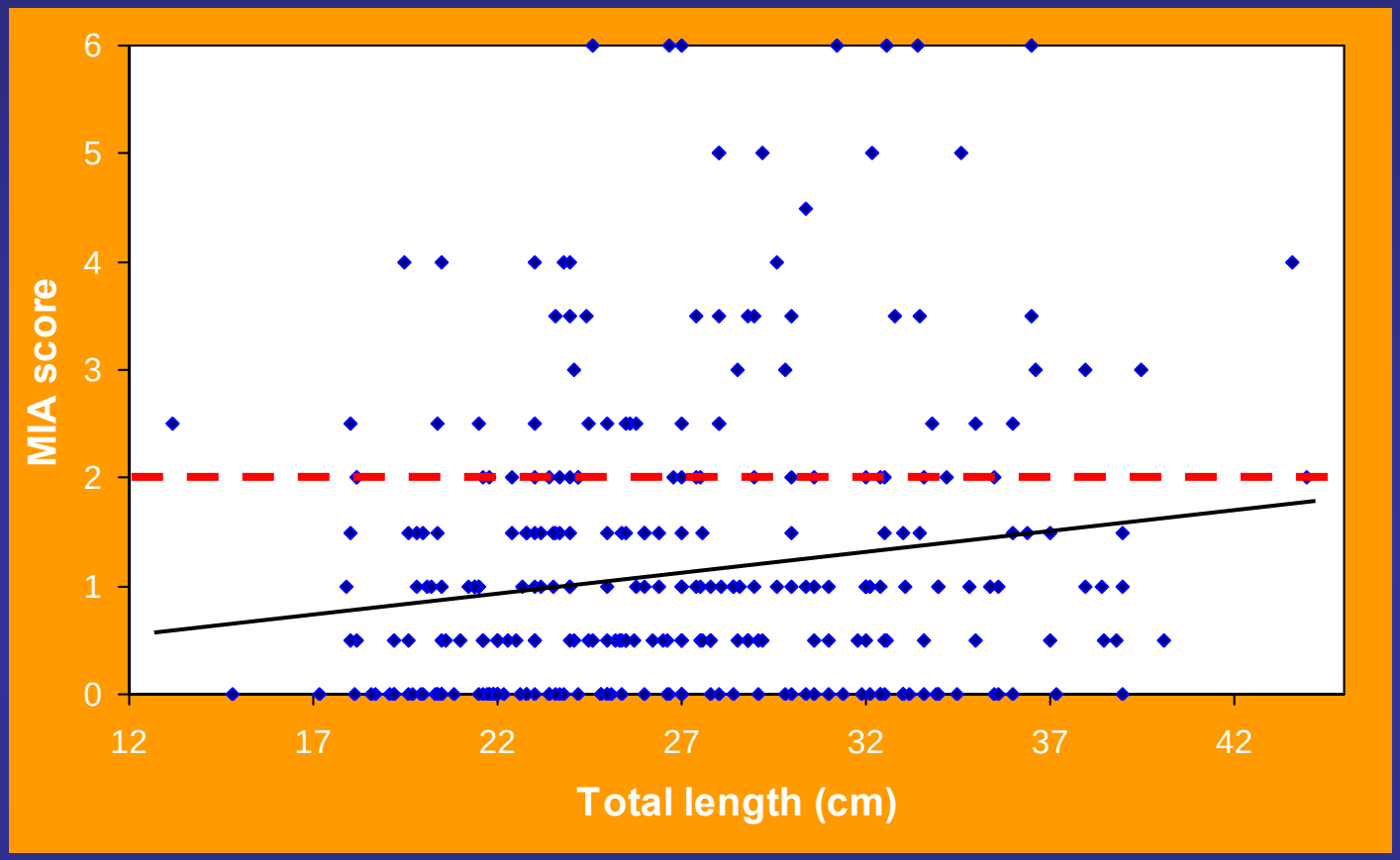



# Geographic patterns – smaller scales



# Correlation of roi size & toxicity




→ Significant positive correlation of roi TL & toxicity (ANCOVA, $p_{roi\ SL} = 0.03$).

→ Variability in toxicity explained by TL very low ($r^2 = 1.5\%$).

# Ciguatera conclusions

1. ***Is roi as toxic as perceived by reef users?***

→ Yes, it is!

(→ Prevalence of toxic roi in the range of species in HI & elsewhere banned from markets.)

# Ciguatera conclusions

## *2. Are there predictable patterns in toxicity?*

- **Geographic:**

→ Oahu vs. Hawaii: prevalence of toxic roi much lower (8% vs. 24%).

→ Within island: no clear patterns between or within coastlines.

→ Large variability in toxicity within sites.

→ Only 2 of 17 sites without any unsafe roi in sample, & sites with low mean toxicity often with toxic outliers.

- **Correlation with roi size:**

→ Very weak positive correlation between fish length & toxicity.

→ Understanding of what makes a roi toxic remains incomplete.

# Ciguatera conclusions

**Key management question:**

*Feasibility of Roi fishery in Hawaii*

→ Data suggest that a low-risk roi fishery is not feasible.

# Feeding biology

1. ***What does roi feed on in Hawaii?***

   → **Stomach content analysis**

2. ***How much prey is consumed by roi populations?***

   → **Population consumption estimation**

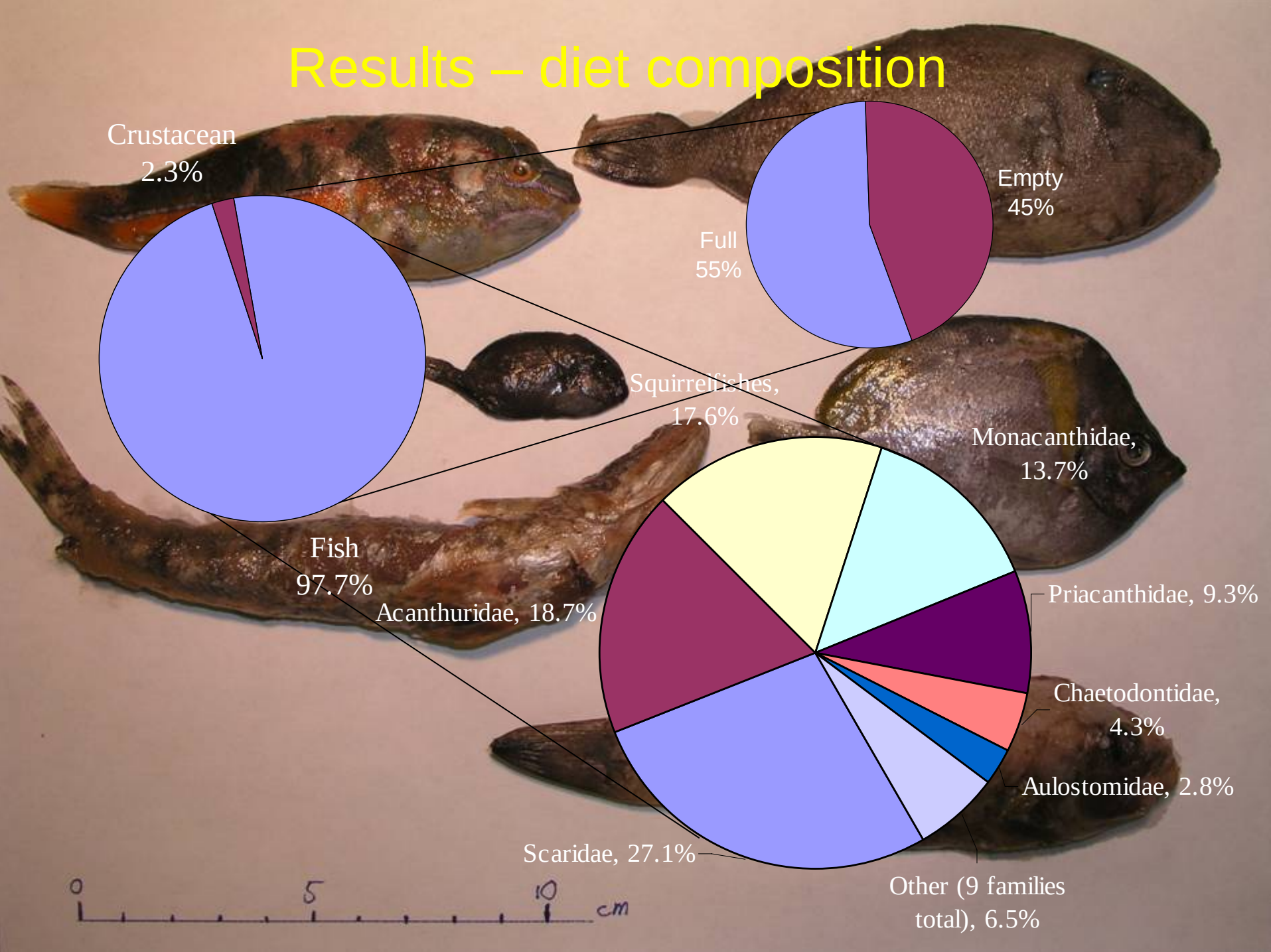
Management issue: • Evaluation of roi impact

# Stomach content analysis

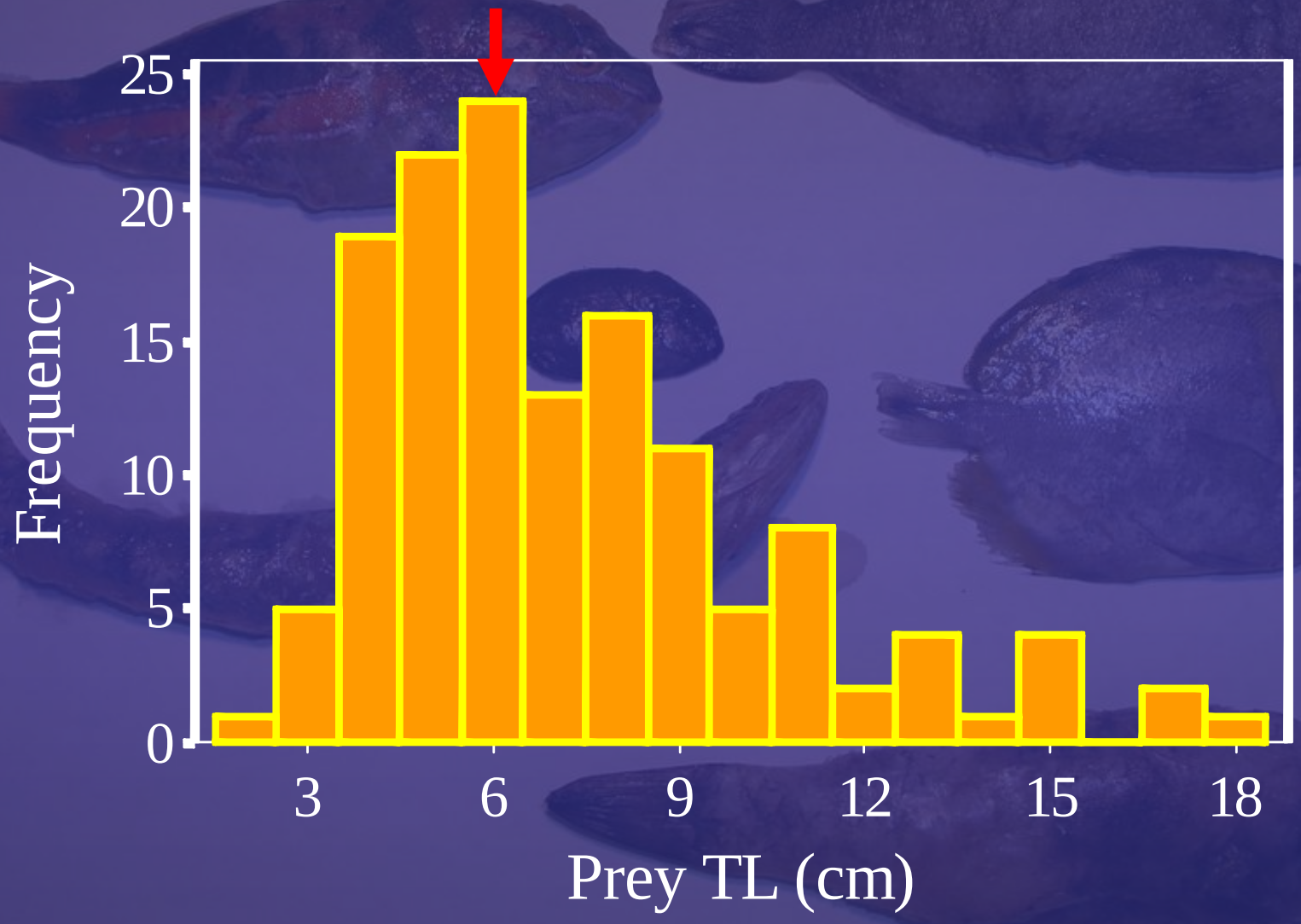
## Sampling

- Same sample of 292 roi from 17 sites.

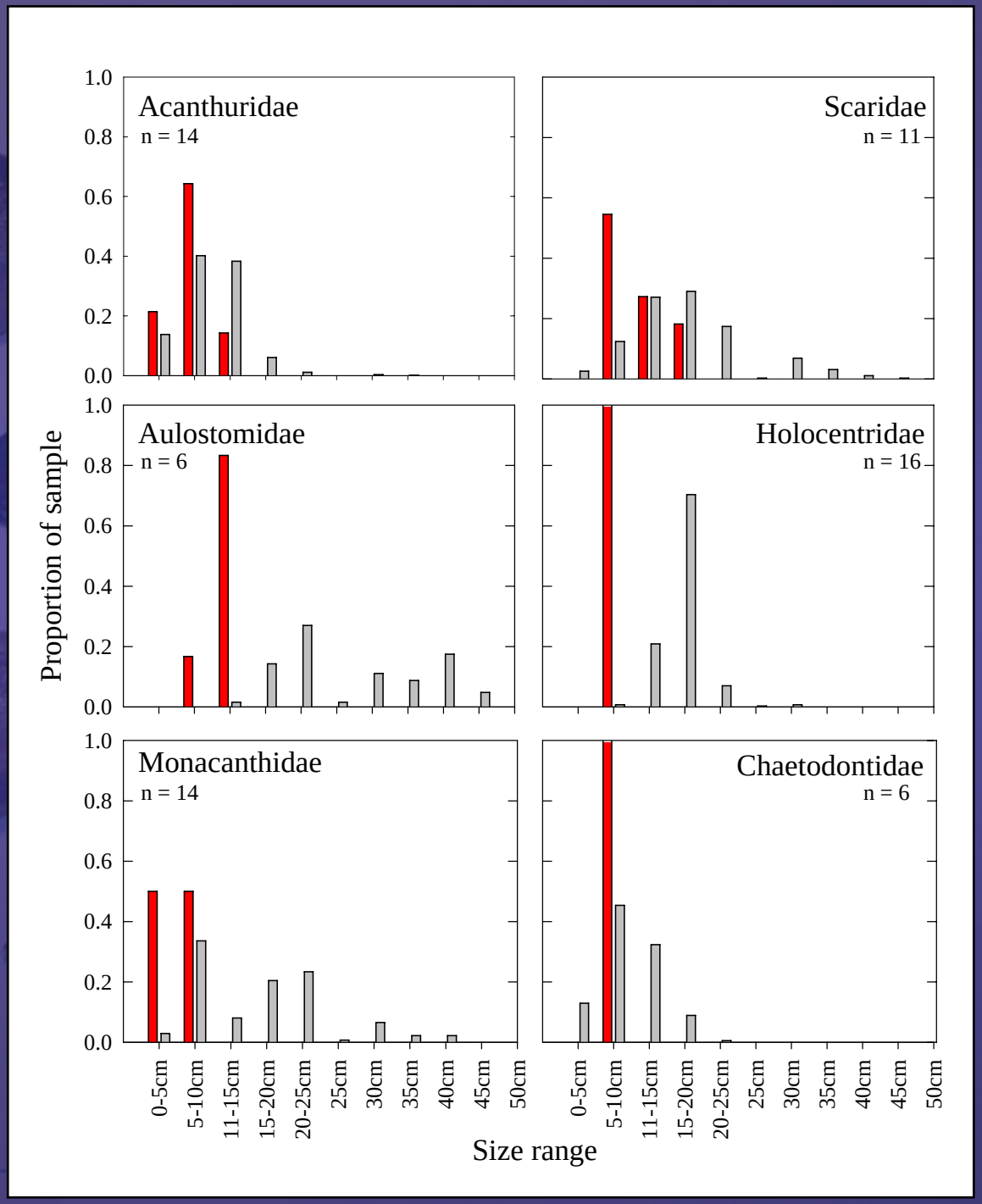
# Results – diet composition



# Results: size composition

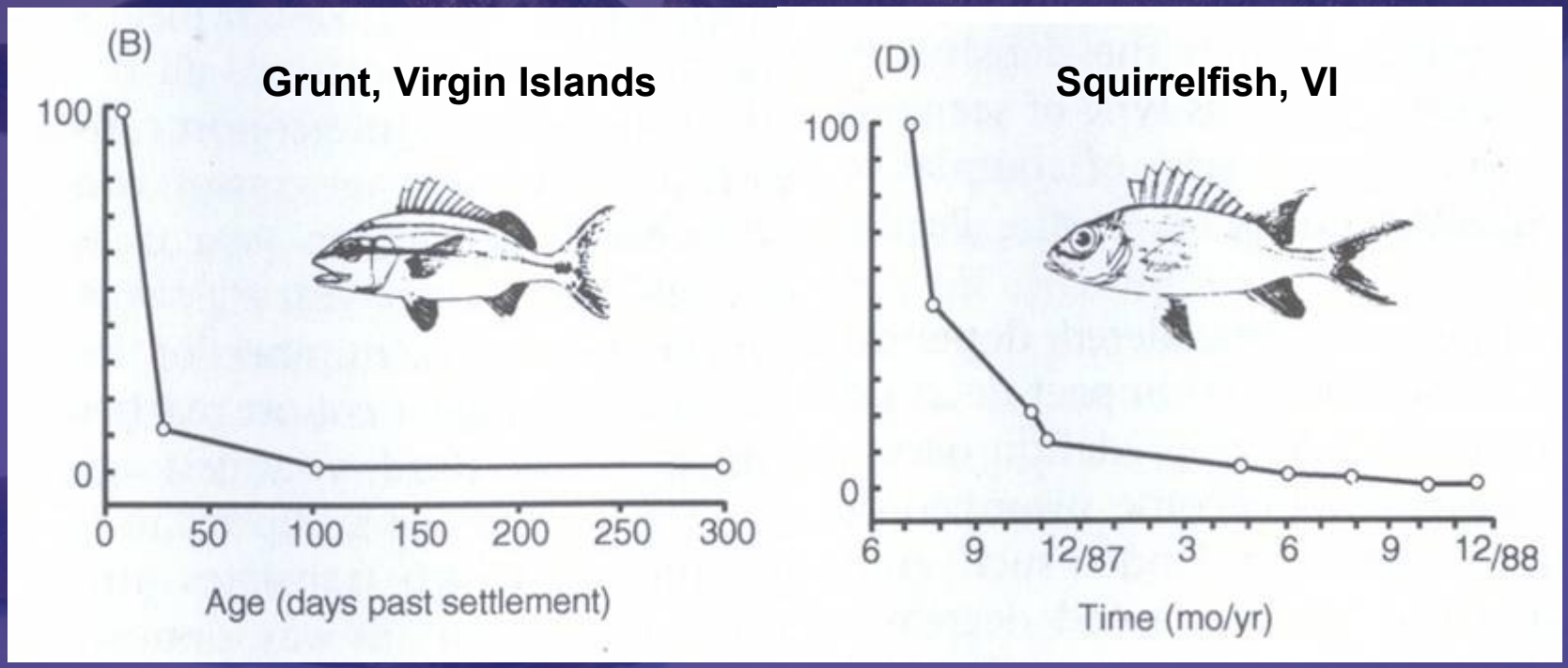


# Size by family:




(Wild abundances from DAR monitoring data)

# Mortality patterns in reef fish




Survivorship (%)

(Hixon 1991)

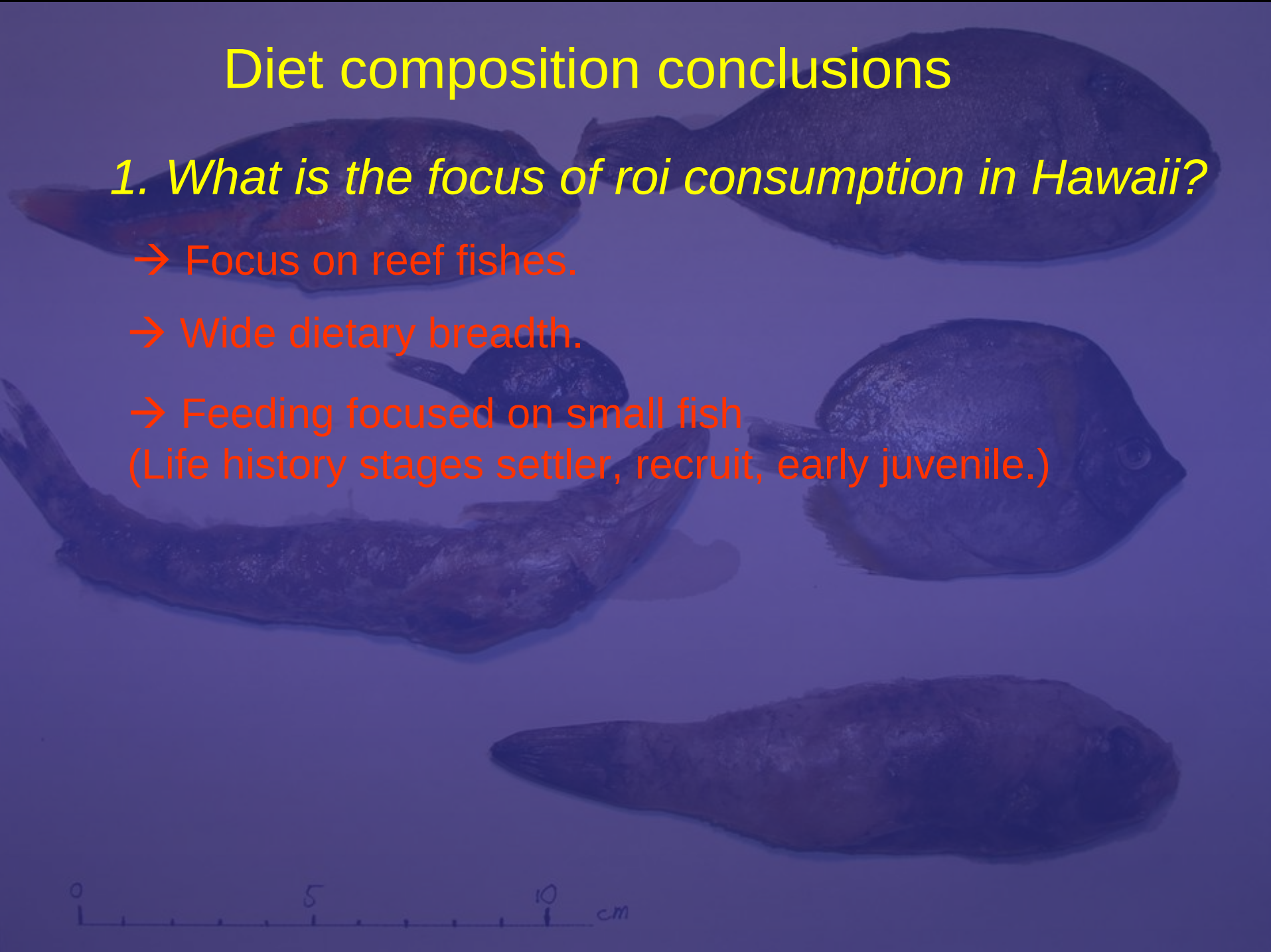
# Diet composition conclusions

*1. What is the focus of roi consumption in Hawaii?*

→ Focus on reef fishes.

→ Wide dietary breadth.

→ Feeding focused on small fish
(Life history stages settler, recruit, early juvenile.)



# Population consumption estimate

J. Dierking, C. Birkeland (UH), I. Williams, W. Walsh, K. Stamoulis (HDAR)

# Background

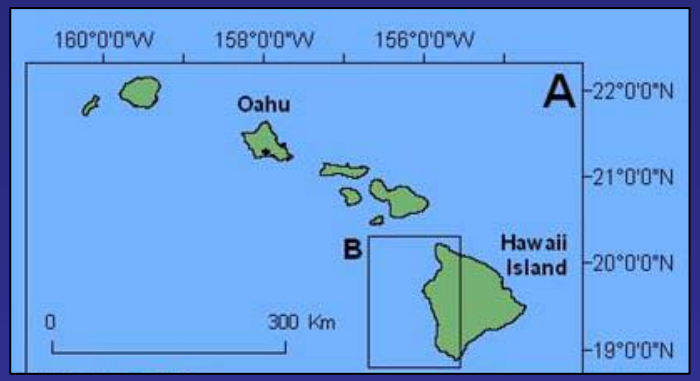
## Previous applications:

- Freshwater fishes: e.g. Brown trout (Jensen et al 2006)
- Marine fishes: e.g.:
  - piscivores in NE Atlantic (Overholtz et al 2000)
  - dolphinfish in E Pacific (Olson & Galvan-Magana 2000)
- Coral reef fishes: 1 (one) published study on consumption by populations of two grouper species in Australia (Beukers-Stewart & Jones 2004)

**Goals:**

- Quantitative impact estimation.
- Comparison with fisheries take.
- Comparison with prey fish stocks.
- Adding to ecosystem level understanding of marine systems (e.g., component of Ecopath model).

# Analysis area



- **167 km stretch of the Kona coast**
- **Reef habitat, 10-17m depth**
  - One of few areas with sufficient data availability.
  - Important collection area of the aquarium fish industry (→ comparison).

# Roi consumption - Method

**Annual consumption** = Total abundance * daily individual consumption * 365

(Bromley 1994)

## Component 1

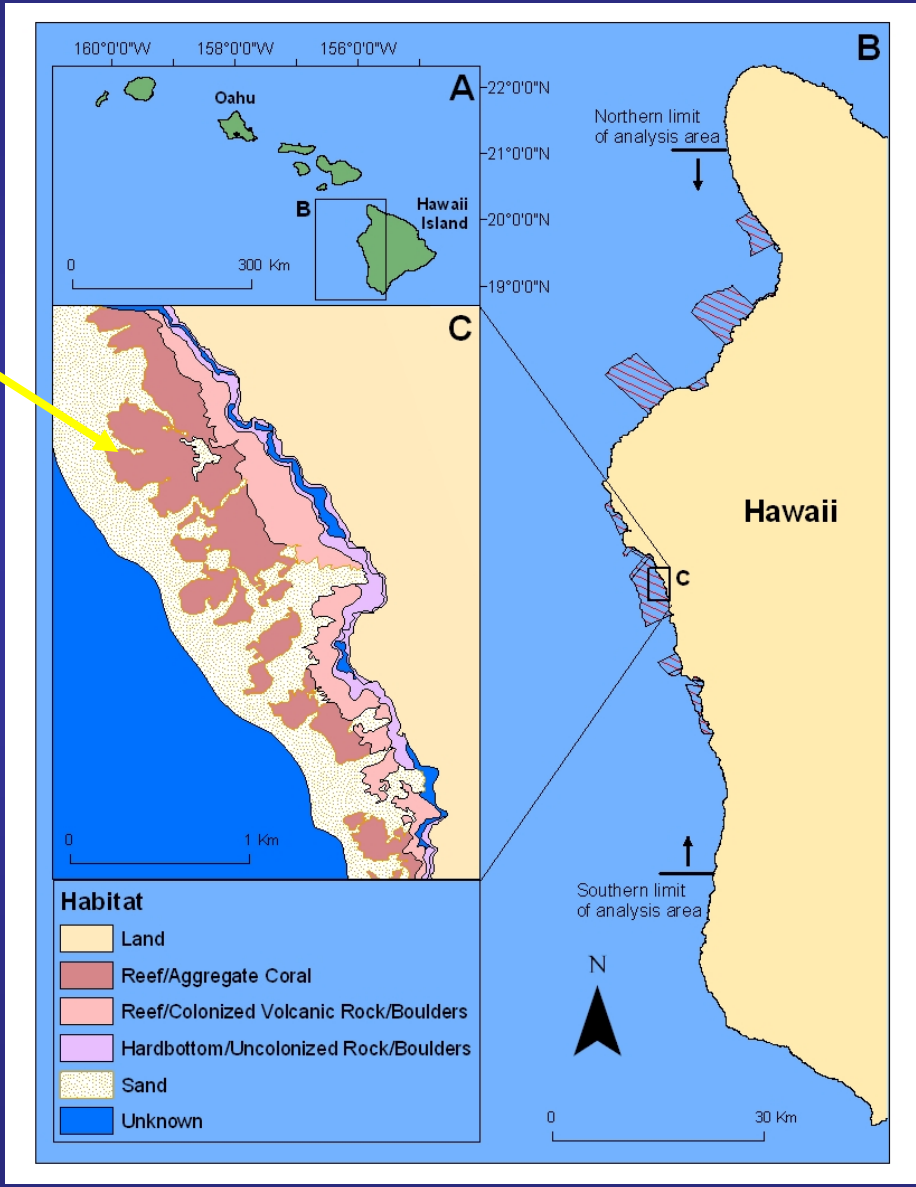
Population size = Area * density

(Friedlander & DeMartini 2002)

# Component 1 – roi population size

## 1. Habitat extent

- From NOAA benthic habitat maps



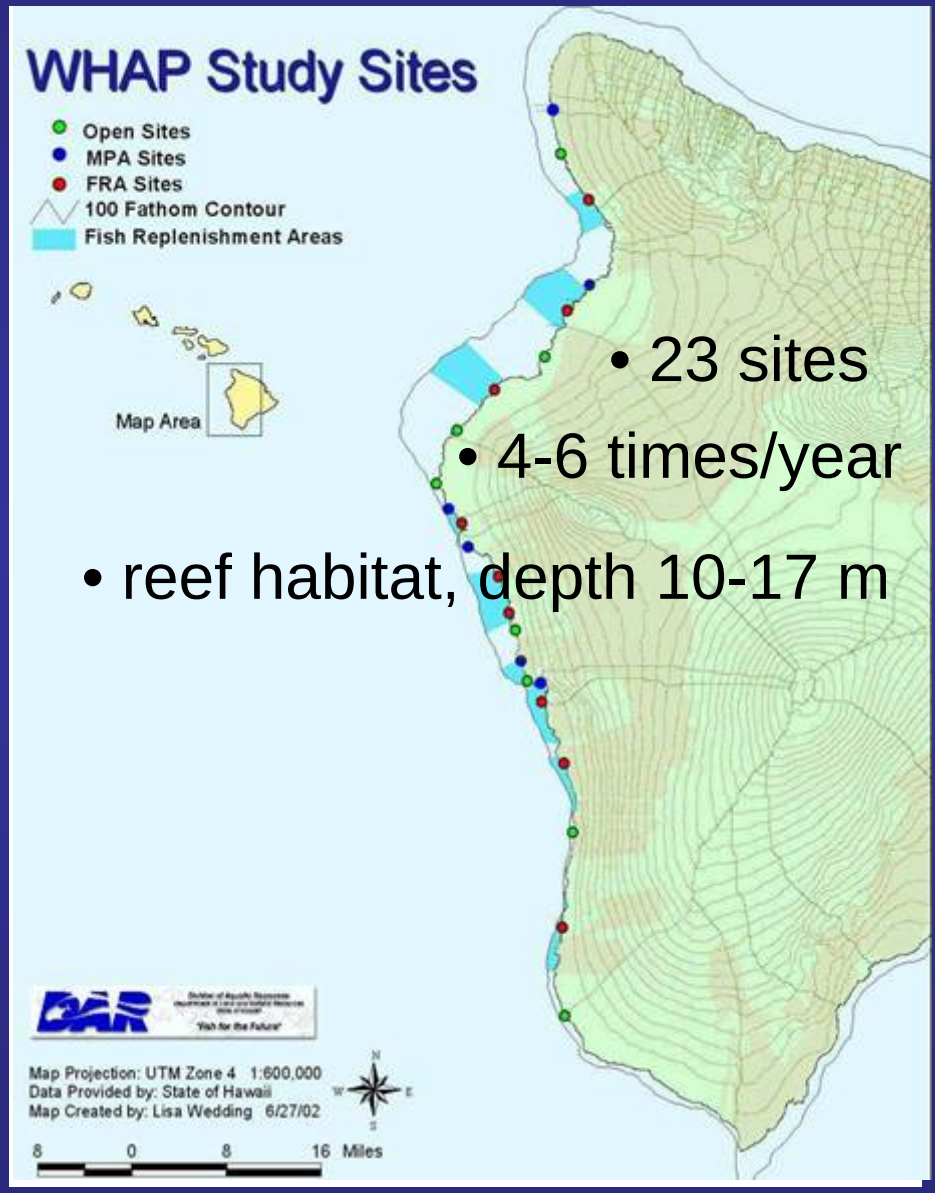
# Component 1 – roi population size

## 1. Habitat extent

- From NOAA benthic habitat maps

## 2. Roi densities

- From DAR fish monitoring data.




- 23 sites
- 4-6 times/year
- reef habitat, depth 10-17 m

# Roi consumption - Method

**Annual consumption** = Total abundance * daily individual consumption * 365

## Component 1

Population size = Area * density

## Component 2

**Daily consumption** = 24h x gastric evacuation rate x mean stomach content

(Bajkov 1935 modified by Eggers 1979)

# Component 2: daily individual consumption

## 1. Gastric evacuation rate

Based on:

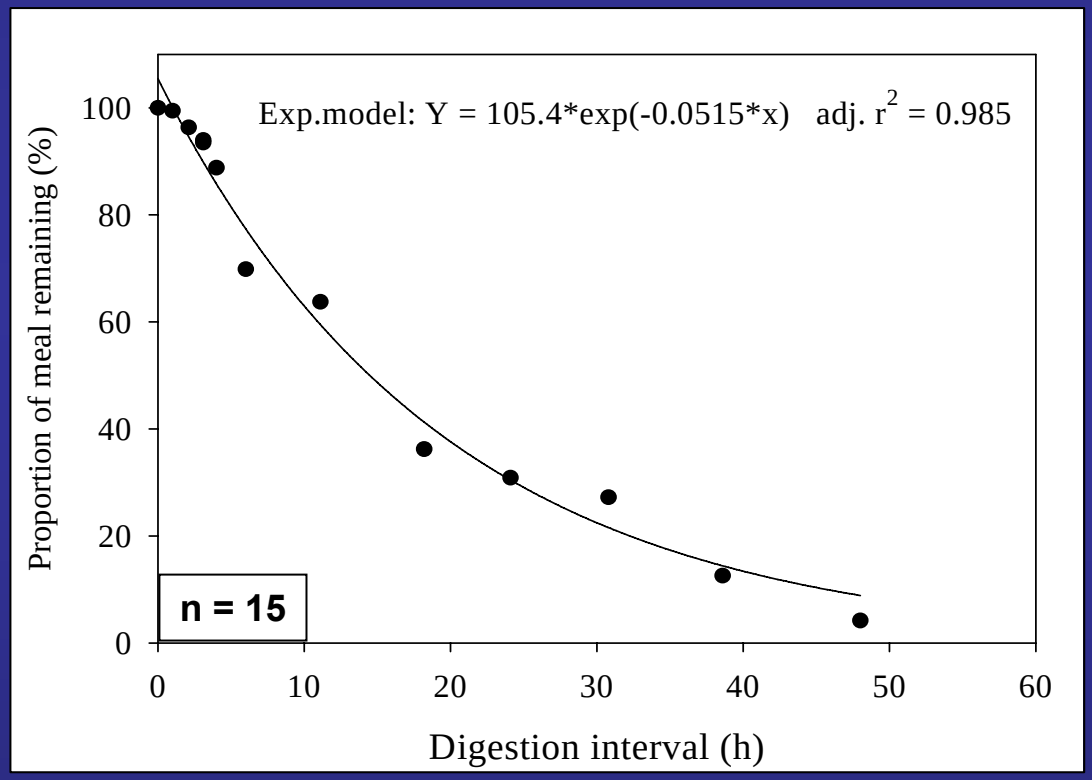
Tank experiments with live roi (serial-slaughter method, Elliott & Persson 1978).

# Component 2: daily individual consumption

## 1. Gastric evacuation rate

Based on:

Tank experiments with live roi (serial-slaughter method, Elliott & Persson 1978).




## 2. Average stomach fullness → avg. content of 292 stomachs

# Population consumption – Results

**Annual consumption** = Roi abundance * daily individual consumption * 365

Component 1

**N roi** = Area * density

Component 2

**Daily consumption** = 24h x gastric evacuation rate x mean stomach content

# Population consumption – Results

**Annual consumption** = 56,292 roi * 0.8% of own body W/day * 600g * 365 **=**

**N roi** = 784 ha * 71.2 ind/ha = 56,292

(C.I. 41,500 – 71,085)

**→ Tuna, dolphinfish: 6% (e.g., Olson & Galvan-Magana 2002).**

**Daily consumption** = 24h x 0.0515*$h^{-1}$ x 0.64% = 0.8% of own body W/day

(C.I. 0.65% - 0.97%)

# Population consumption – Results

**Annual consumption** = 56,292 roi * 0.8% of own body W/day * 600g * 365

**= 99 metric tons ≈ 8.2 million reef fish/year**

In other terms:

**Consumption = 12 metric tons/km$^2$** (99 metric tons per 784 ha)

**≈ 1 fish/m$^2$** (8.2 million fish per 784 ha)

# Discussion

## Putting the numbers in perspective.

Consumption versus …

1. previous studies.
2. Aquarium fish industry take.
3. Standing stock of reef fishes.

# Roi consumption vs. other reef fish predators

| Species | Consumption/km$^2$ | Source |
|---|---|---|
| *C. argus* | 12 metric tons | This study |
| *C. boenak* & *C. cyanostima* | 16 metric tons | Beukers-Stewart & Jones 2004 |

- *C. boenak* & *C. cyanostigma* were important in regulating community structure.
- Similar consumption by roi suggests that it is playing an important role.

# Consumption vs. Aquarium fish industry take

| | Consumption (t) in open areas only | | |
|---|---|---|---|
| | roi | AFI | roi vs AFI |
| Yellow Tang | 1.0 | 3.0 | 33% |
| Acanthuridae | 4.9 | 3.6 | 137% |
| All fishes | 41.1 | 3.7 | 1,100% |
| Avg size: | 11 g | 25 g | 43% |

→ Roi consumes substantial amounts of reef fish biomass vs. AFI take.

→ Feeding is focused on much smaller sizes than AFI take.

# Consumption vs. prey fish standing stock

| | Consumption | Stock | C vs. Stock |
|---|---|---|---|
| Biomass (t) | 93.7 | 836 | 11% |
| Number (million) | 8.2 | 11.4 | 72% |
| Size (g) | 11.4 | 73.5 | 16% |

→ Biomass removed substantial.

# Feeding biology conclusion

*1. What is the focus of roi consumption in Hawaii?*

→ Small reef fish individuals (→ settlers, recruits, early juveniles)

*2. How much prey did roi consume in our analysis area in 2003?*

→ 8.2 million reef fish weighing 93.7 metric tons.

# Feeding biology conclusion

## Management issue:

Evaluation of effects of roi consumption

- Consumption may not directly translate into ecological impact.
  - At the same time, comparison of roi consumption with …

    1. the available study from the literature
    2. the standing stock size of reef fishes
    3. the take of reef fish by the aquarium fish industry

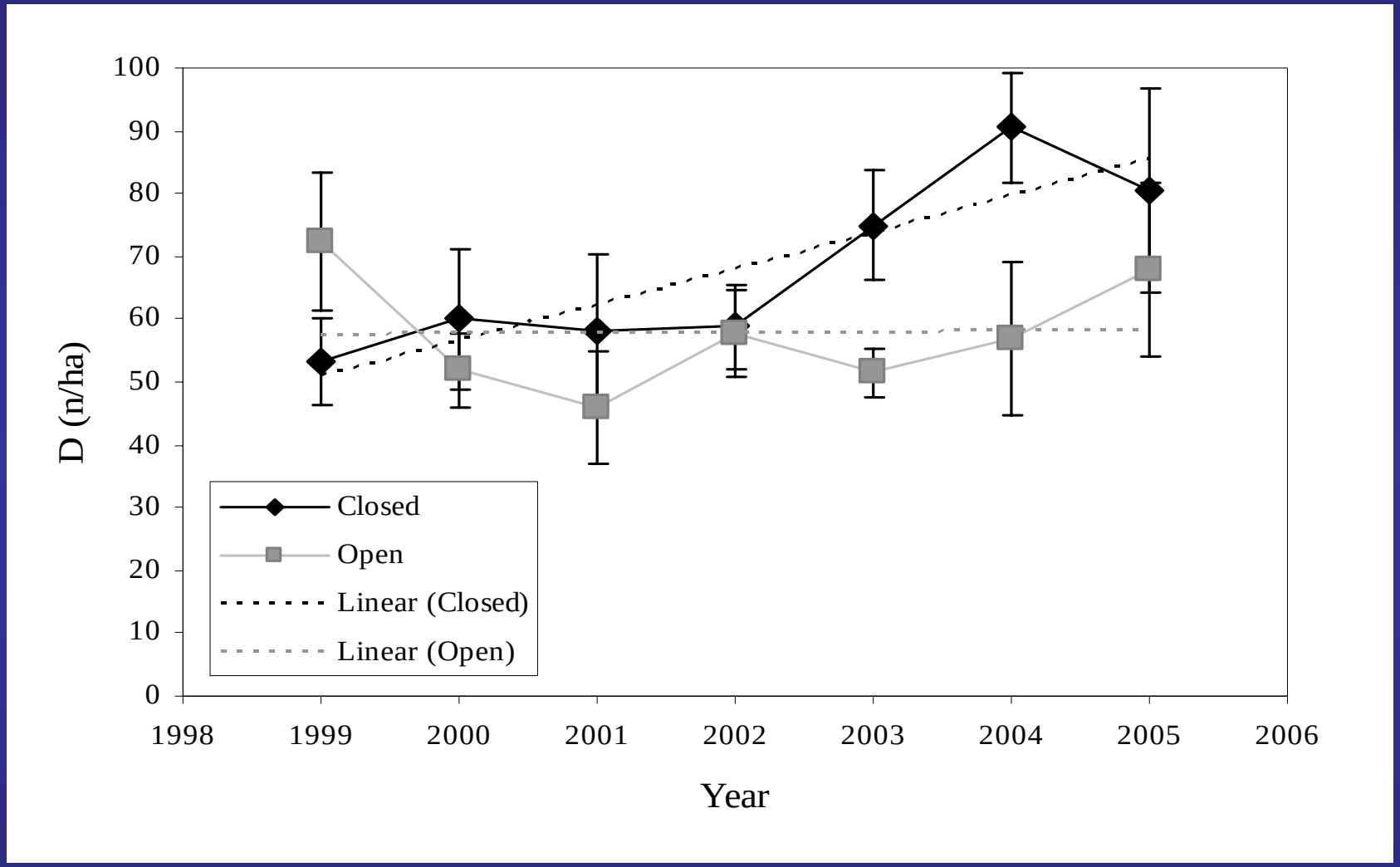
… suggests that roi consumption is an important factor in the reef ecosystem in Hawaii.

# Future work

**Trends in fish abundance, Kona coast, 1999 – 2005 (DAR surveys)**

| Taxon | Closed | Open |
|---|---|---|
| Total fish community | ++ | +/- |

# Future work


100
90
80
70
60
50
40
30
20
10
0
D (n/ha)
1998
1999
2000
2001
2002
2003
2004
2005
2006
Year
Closed
Open
Linear (Closed)
Linear (Open)

# Future work

**Trends in fish abundance, Kona coast, 1999 – 2005 (DAR surveys)**

| Taxon | Closed | Open |
|---|---|---|
| Total fish community | ++ | +/- |
| *Cephalopholis argus* | ++ | - |

**Preferential feeding**

# Acknowledgements

My committee: Charles Birkeland, Ivor Williams, Sheila Conant, Bob Kinzie, Yoshitsugi Hokama

Collaborators: Bill Walsh, Kosta Stamoulis

Help on the project & on my way: Amanda Meyer, Tim Clark, Lance Smith, Shawn Fujimoto, Jim Parrish, Brett Schumacher, Jeremy Claisse, Sasa Satele, Brittany Graham, Jamie Tanimoto, Terri Rust, Brian Popp, Albert Tacon, Joanne Leong, Steve Cotton, Brent Carmen, Randy Kosaki, Risa Minato, Kristine Davidson, Mike Hamnett, Dave Pence, Kevin Flanagan, Kerwin Lum, Lucy Kida, Audrey Shintani, Jan Tatsuguchi, Lynne Ogata, Shannon Oshiro, Neil Sarver, Dale Simms, Martha Staff, and Tom Koerber.

Special thanks to:
Chuck, my parents, Katja, Judy, Amanda, John, and to Hawaii, a very special place.

***Mahalo!***

Funding:

- **HCRI**
- UH EECB program
- HIMB (logistical support)

Mahalo!
Questions?