CLIMATE CHANGE AND CORAL REEF FISH AND FISHERIES

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Greenhouse gas concentrations

- CO$_2$ increased ~40% in 250 years
- 280ppm pre-industrial
- 390ppm now
Enhanced Greenhouse Effect

- Average surface temperature highest for >1000 years
- Average ocean temperature increasing
- Tropical SST increased ~0.5C 1871-2007
Last decade hottest on record

Tropical annual SSTs: 10-year averages

Data source: HadISST

Janice Lough AIMS
The other CO₂ problem

- Ocean acidification
- 30% of excess CO₂ absorbed by the ocean
- Ocean becomes more acidic and changes carbonate chemistry

pCO₂, carbonic acid, bicarbonate, H⁺

carbonate, pH (-logH⁺)

Hoegh-Guldberg et al. 2007
• Ocean pH dropped 0.1 units since pre-industrial
• pH could drop another 0.3-0.4 units by 2100 depending on emissions
• Problem for marine calcifiers: corals, sea urchins, molluscs
Carbon dioxide emissions tracking high-end scenarios

Raupach et al 2007, PNAS; Global Carbon Project 2009, Canadell June 2009
## Projected climate changes by 2100

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Global surface temperature</td>
<td>Increase 2-4°C (6°C)</td>
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<tr>
<td>Sea surface temperature</td>
<td>Increase 1-3°C</td>
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<tr>
<td>Tropical storms</td>
<td>Stronger</td>
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<tr>
<td>Droughts and floods</td>
<td>More extremes</td>
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<tr>
<td>Sea level</td>
<td>Increase up to 0.6m</td>
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<tr>
<td>Ocean pH</td>
<td>Decrease 0.3-0.4 units</td>
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Impact on coral reef fishes

• Indirect: Habitat degradation
  – Diversity and abundance
  – Species composition
• Direct: Individual performance
  – Population sustainability
  – Population variability
  – Life histories (size & growth)
• Range shifts
• Productivity changes

Munday et al. 2008. Fish and Fisheries 9, 261-285
Climate change & habitat degradation

- Warming ocean
  - Mass coral bleaching
- Ocean acidification
  - Reduced calcification
- Stronger storms
  - More physical damage
- Loss of coral cover
- Shift in community composition - resilient species
Declining health of coral reefs

• Over 30% of world reefs seriously degraded
• Declining coral cover

Gardner et al 2003 Science 301, 958-960
Bruno & Selig 2007 PLOSOne e711
Coral loss

- 10% of fishes are coral dependent
- Directly affected by coral loss
Coral loss

• But, 75% of species declined following coral decline

• 50% of species declined by >50%

• Small juveniles live in or near live coral

Jones et al. 2004. PNAS. 101: 8251-8253
Proportional change

Time after mass bleaching (years)

0       1       2       3       4        5       6       7        8       9      10

0.5

0

-0.5

-1

Coral reef fishes

Macroalgae

Coral cover

Habitat complexity
Resilience and recovery

Coral cover and fish populations recovered over 8 years to near pre-disturbance abundances

Regime shift

Post-bleaching regime shift on patch reefs
Fewer specialist and more generalist species

Coral loss and fish communities

- Depends on frequency and size of disturbances
  - recovery cycles
- Fewer species
  - coral dependent species lost first
- Lower abundances
  - loss of settlement habitat & shelter
- Changed fish communities
  - more generalists
  - Roving herbivores often increase in abundance (e.g. surgeonfishes). May be important in removing algae and facilitating reef recovery.
- Incomplete recovery and regimes shifts likely
Direct Effects: Temperature

- Most reef fishes not living near lethal thermal limits
- Ectotherms - temperature affects physiological condition, development, growth rate, reproduction
- Tropical species sensitive to temperature change
Growth

- Reared at summer:
  - average 28.5°C
  - minimum 26°C
  - maximum 31°C
- Lower growth at higher temperature
- Adults lost weight at 31°C
- Already at thermal limits during summer

Reproduction

- Reduced spawning
- Reduced clutch size
- Reduced egg size
- Reduced offspring size

Donelson et al. 2010 MEPS In press
Reproduction

- Confined to narrow temperature range (5°C)
- Breeding cued by temperature in some species - earlier breeding
- Reproductive output could be retarded
- Consequences for population replenishment

Ruttenberg 2005 Oecologia 145: 394-403
Larval survival

- Faster development = higher survival
- But, planktonic food supply affected by warmer water
- More extremes in number of larvae surviving to replenish adult populations
- Harder to manage fisheries

![Graph showing the relationship between near-reef water temperature and recruit density. The equation is given as $y = 0.0481x - 0.9809$ with $R^2 = 0.61$.](image)
Range shifts

- Widely recorded for temperate and polar fishes
- Tropical species being found at higher latitudes

Fig. 1. Examples of North Sea fish distributions that have shifted north with climatic warming. Relationships between mean latitude and 5-year running mean winter bottom temperature for (A) cod, (B) anglerfish, and (C) snake blenny are shown. In (D), ranges of shifts in mean latitude are shown for (A), (B), and (C) within the North Sea. Bars on the map illustrate only shift ranges of mean latitudes, not longitudes. Arrows indicate where shifts have been significant over time, with the direction of movement. Regression details are in Table 1.

Perry et al. 2005 Science 308:1912-1915
Range shifts

- Increase or decrease
- Existing range
- Thermal tolerance

Munday et al. (2008). Fish and Fisheries 9 261-285
Life histories

- Correlated with temperature
- Populations in warmer water
  - shorter lived
  - smaller maximum size
  - earlier maturation
- Shifts in local populations
- Consideration for fished stocks
  - quotas and size limits

Robertson et al 2005 MEPS 295: 229-244
Temperature

- Effects on growth and reproduction
- Predict more variable larval supply - consequences for population dynamics
- Range shift as species track thermal preferences
- Habitat availability could limit high-latitude species
- Life-histories of local populations
- Long-term acclimation and adaptation?
Acclimation and adaptation

• Many fishes have geographic ranges that span a large temperature gradient
• Potential for acclimation to increased temperature
• Genetic adaptation influenced by generation time
  – many small fishes live ~ 1 year
  – others live decades years
Climate change and fisheries

- Climate change will interact with fishing
- Habitat loss can have a similar magnitude of effect on abundance
- Larger species affected by reduced prey availability
- Climate change is an additional pressure for fished populations

Fisheries productivity

- Considered thermal tolerance, habitat availability, planktonic productivity to model fisheries productivity
- Increase in some areas decrease in other areas
- Estimate 40% reduction in tropics by 2055

Fisheries productivity

- Greatest effects predicted on continental shelf – coral reefs
- Pacific region more strongly impacted

Ocean pH

- So far only considered temperature
- pH 7.8 by 2100
- Problem for marine calcifiers: corals, sea urchins, bivalves, gastropods
- Important fisheries

IPCC 2007 Chapter 10 Global Climate Projections
Good news!

- Most fish tolerate reduced pH
- No negative effects on:
  - Hatching success
  - Growth
  - Survival
  - Swimming ability

Bad news

- Sense of smell disrupted by low pH
- Larvae use smell to locate adult habitat and avoid predators
- Attracted to sub-optimal habitat and predators

Dixson et al. 2010. Ecol Lett
Impact on coral reef fishes

Complex and difficult to predict!
Impact on coral reef fishes

• Habitat degradation
  – Decreased diversity and abundance
  – Changed species composition

• Individual performance
  – Increased population variability
  – Possible reproduction and recruitment failure
  – Life history shifts (size & growth)

• Range shifts

• Productivity changes – could be significant declines
  – Demands from human populations increasing
Management strategies

• Reduce CO$_2$ emissions
• Increase reef resilience
• Find ways to reduce harvest and reduce reliance on fisheries
• Safety margin to harvest levels to account for uncertainty
• Assist fishers adapt to change
Management strategies

• Pacific Islands climate change vulnerability assessment
• Published later this year
Total abundance of coral and butterfly fishes in Moorea recovered, but community structure was different

Berumen & Pratchett 2006 Coral Reefs 25:647-653