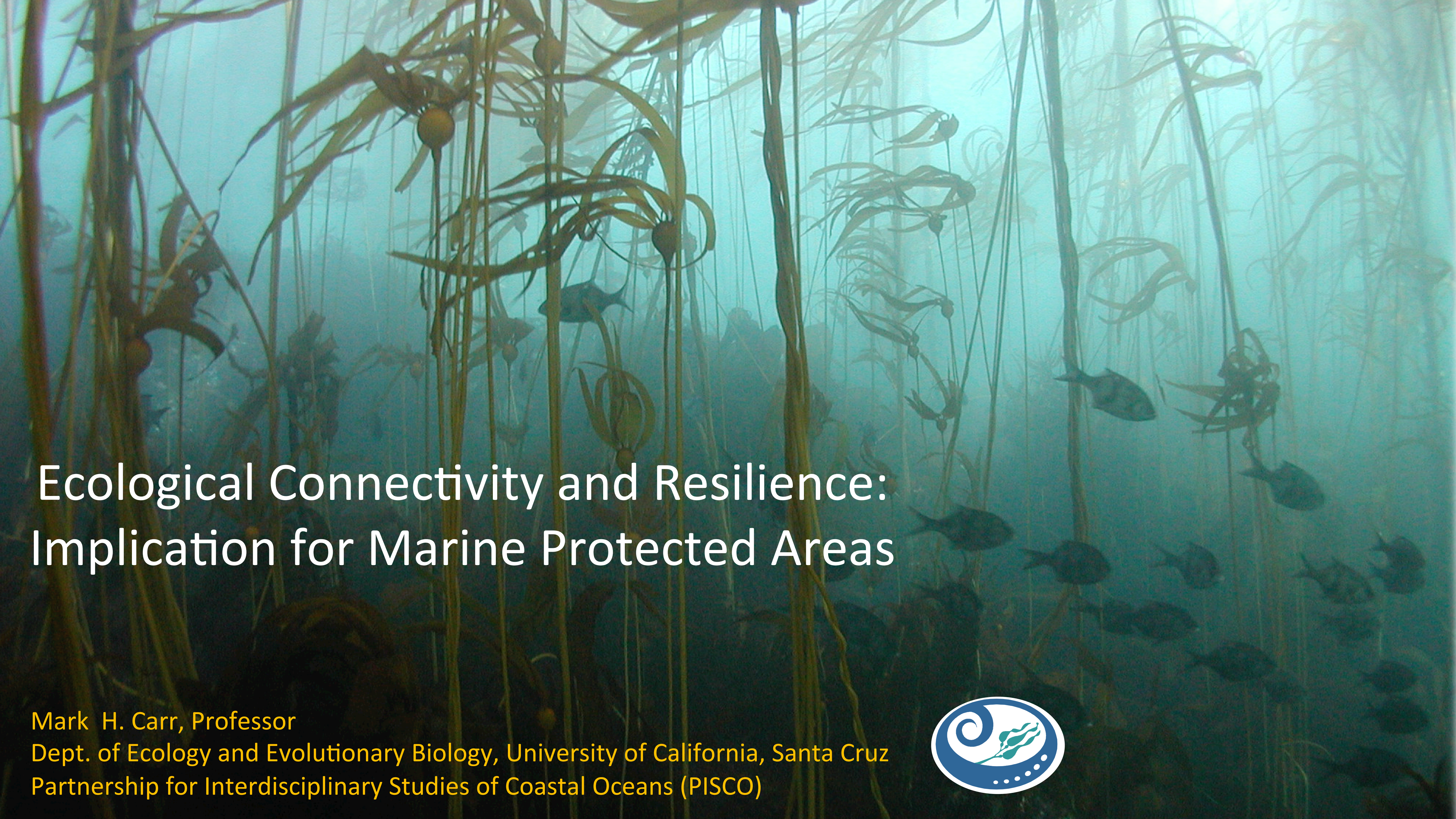
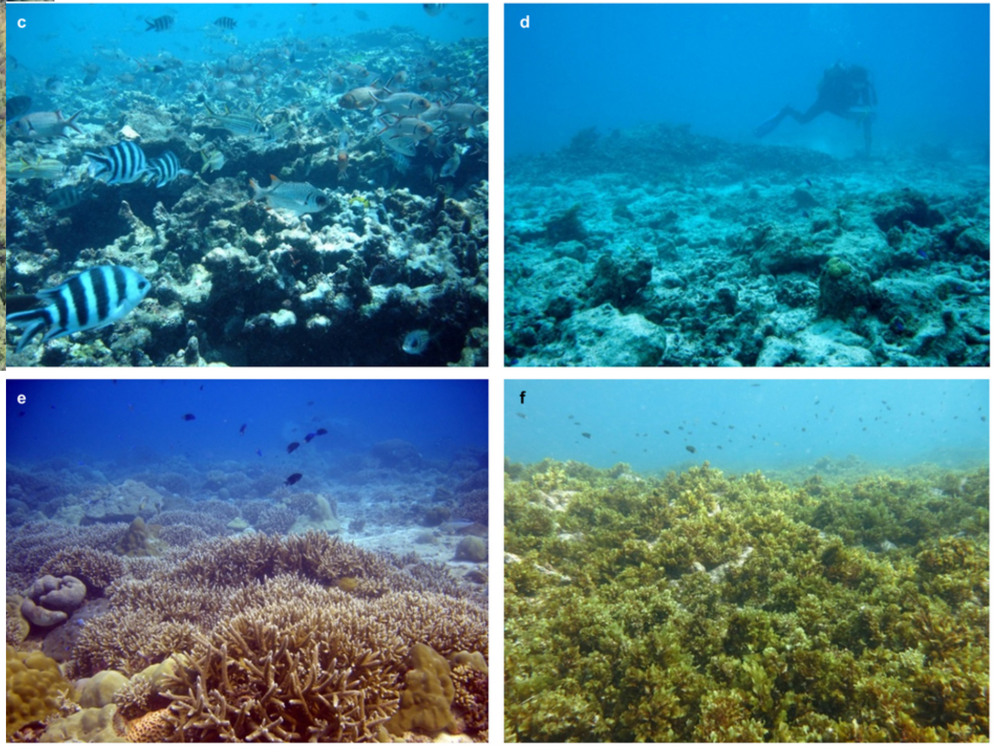


Ecological Connectivity and Resilience: Implication for Marine Protected Areas

Mark H. Carr, Professor
Dept. of Ecology and Evolutionary Biology, University of California, Santa Cruz
Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO)

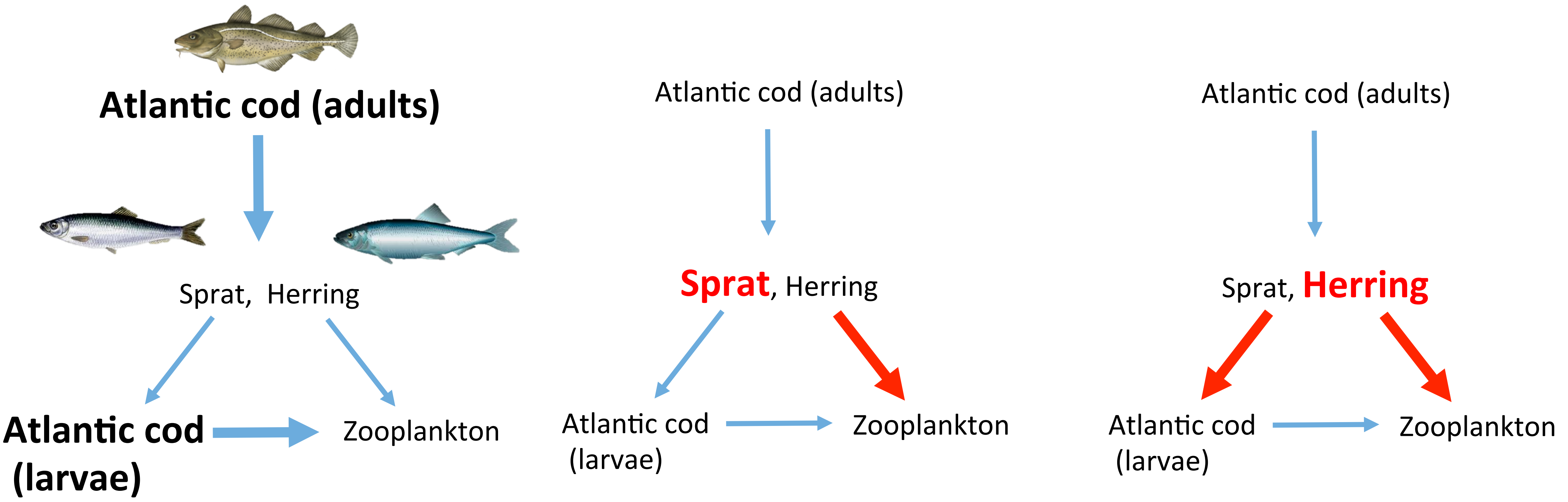
Alternative stable ecosystem states…



versus ecosystem resilience

Alternative stable population states…

Example: Atlantic cod and their pelagic prey (also a nice ecosystem example)



(Frank et al 2005: Scotian Shelf)

(Casini et al 2008: Baltic Sea)
Sprat outcompete cod larvae

(Fauchald 2010: North Sea)
Herring eat and outcompete cod larvae

Why is ecological resilience important?

We have come to value natural populations and ecosystems and the services they provide society.

Therefore, we don't want to undermine the ecological mechanisms that support resilience and ability of these systems to persist and continue to generate services.

What is ecological connectivity?

Ecological spatial connectivity refers to processes by which genes, organisms, populations, species, nutrients and/or energy move among spatially distinct habitats, populations, communities or ecosystems.

The Central Importance of Ecological Spatial Connectivity to Effective Marine Protected Areas and to Meeting the Challenges of Climate Change in the Marine Environment: A Scientific Synthesis

http://marineprotectedareas.noaa.gov/fac/products/

Spatial Ecological Connectivity

Four forms:

1) Population (demographic)

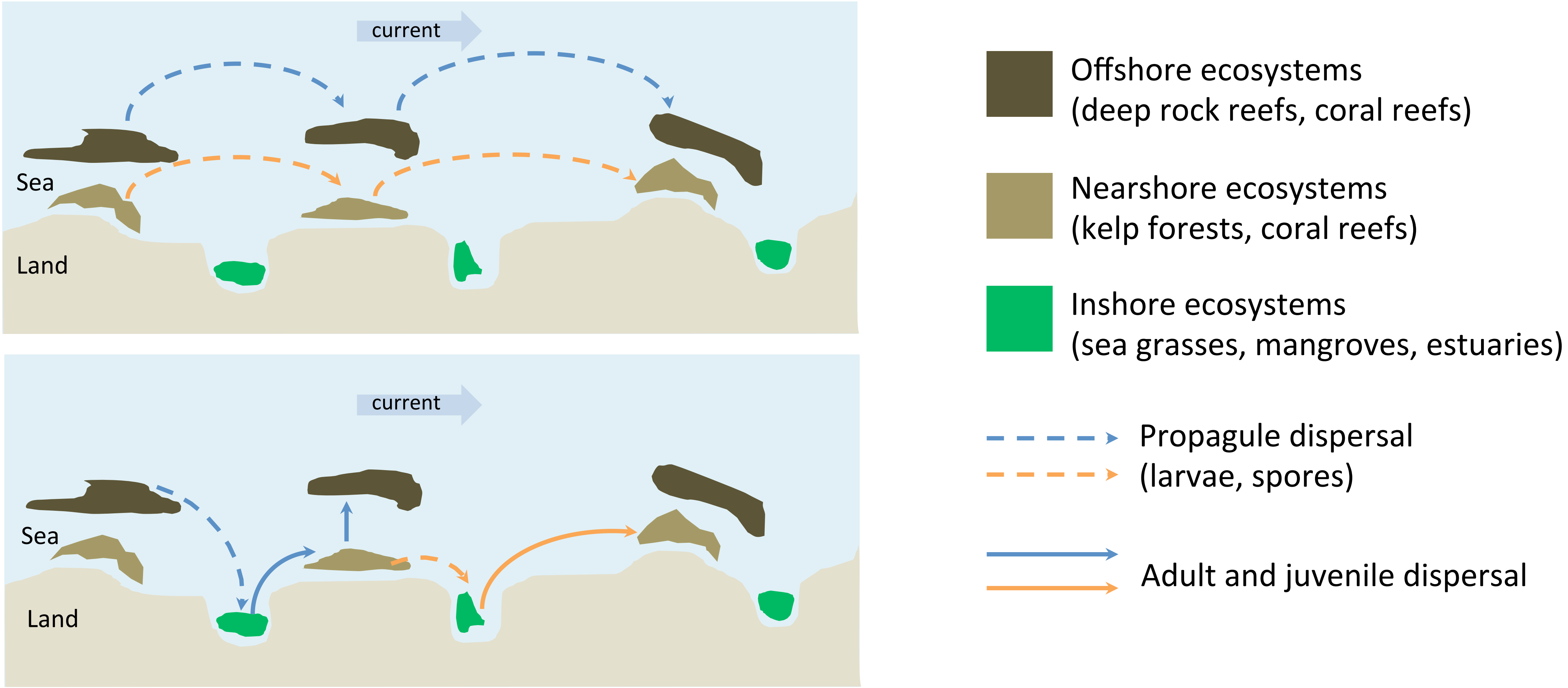
2) Genetic

3) Community

4) Ecosystem

1) Population (demographic) connectivity

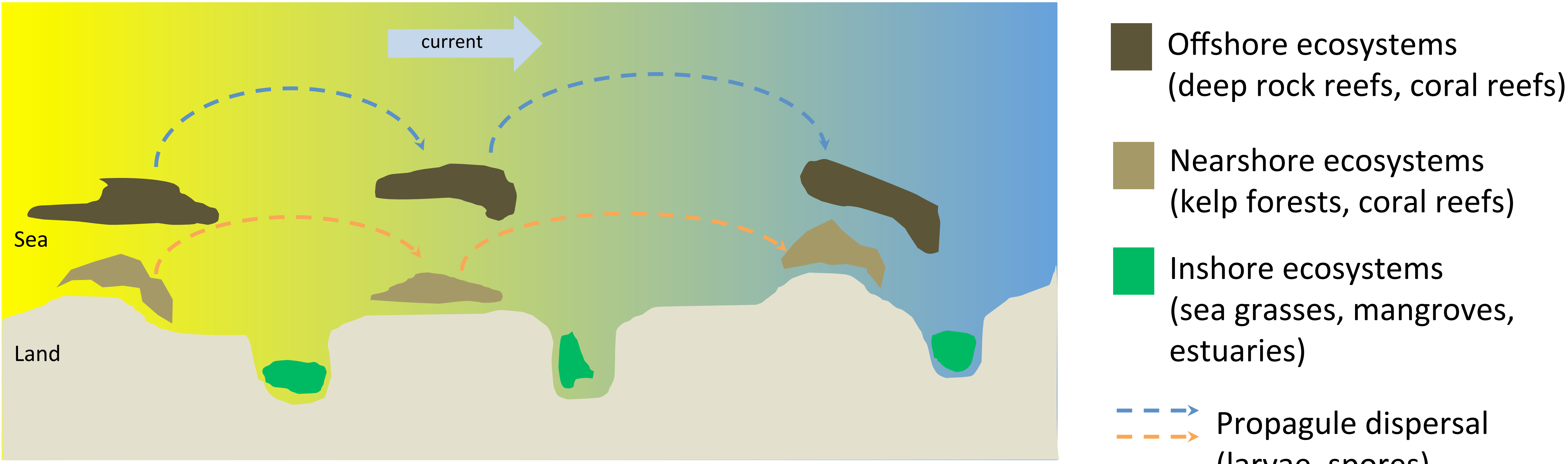
The movement of individuals between populations - metapopulations



Propagule (larvae, spores) dispersal is the fundamental mechanism of connectivity
(contrast with terrestrial and marine mammal populations)

2) Genetic connectivity

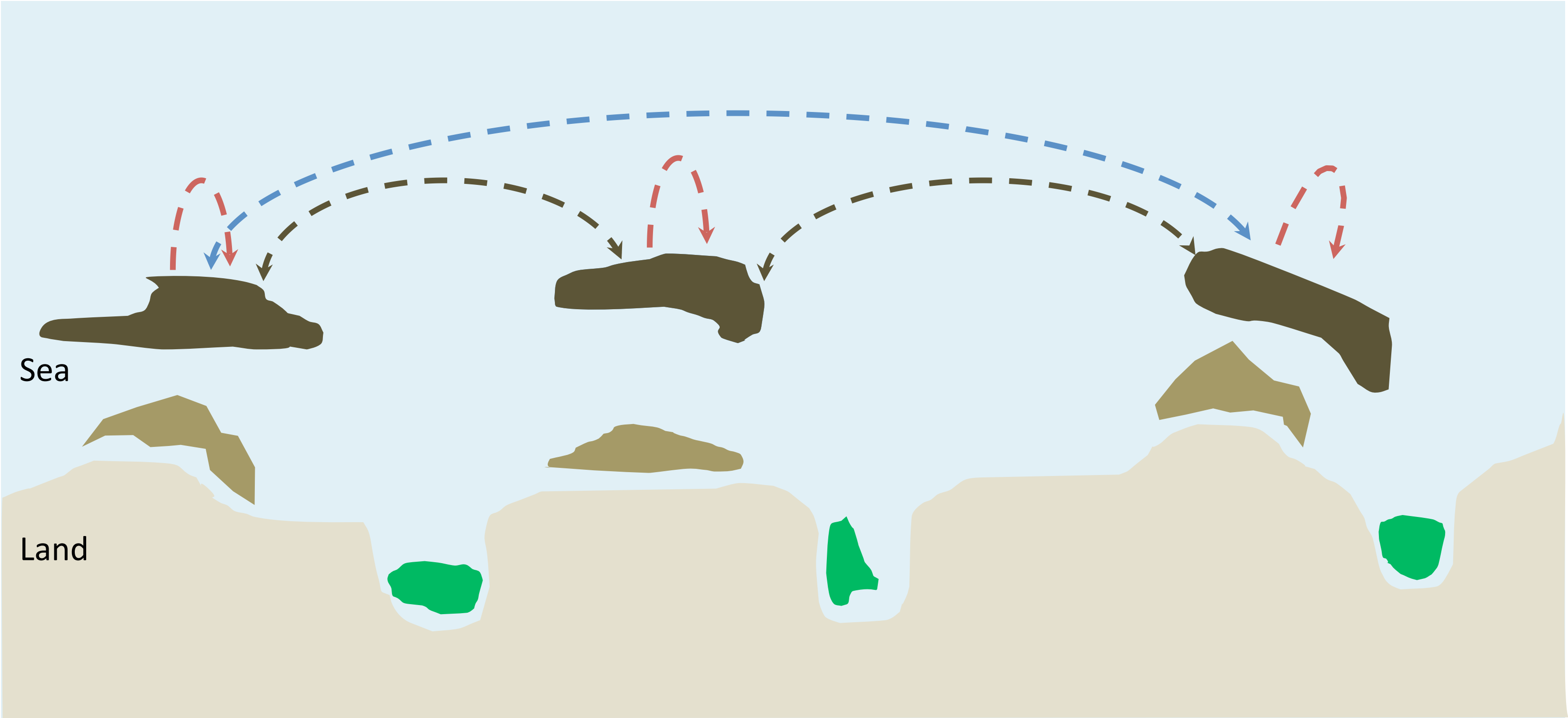
The movement of genes among populations



Genetic composition of a species can vary across environmental gradients and barriers to dispersal

3) Community connectivity

Movement of multiple species between communities - metacommunities



Offshore ecosystems (deep rock reefs, coral reefs)

Nearshore ecosystems (kelp forests, coral reefs)

Inshore ecosystems (sea grasses, mangroves, estuaries)

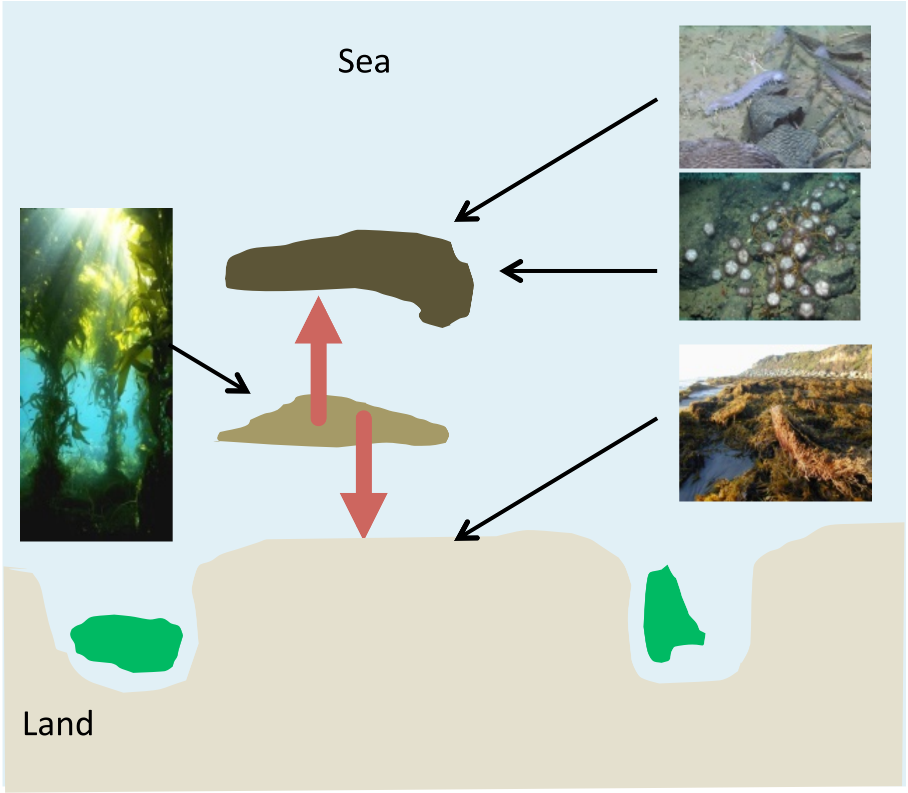
Long-distance propagule (larvae, spores) dispersal

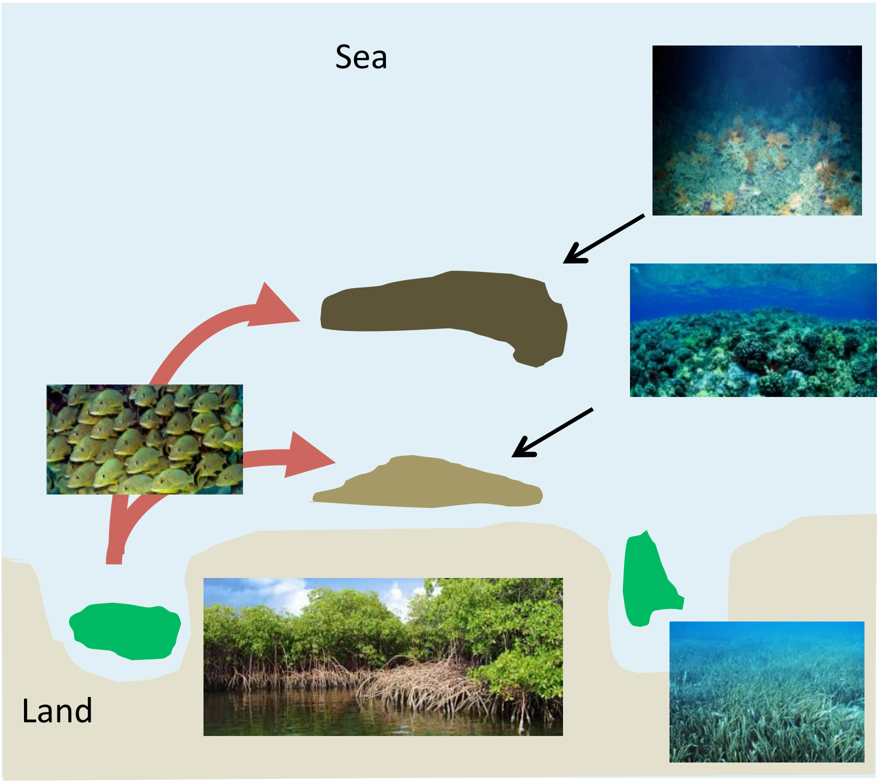
Moderate-distance propagule dispersal

Short-distance propagule dispersal

4) Ecosystem subsidies

The movement of nutrients, materials and organisms between ecosystems





Offshore ecosystems (deep rock reefs, coral reefs)

Nearshore ecosystems (kelp forests, coral reefs)

Inshore ecosystems (sea grasses, mangroves, estuaries)

Movement of material, nutrients, energy and organisms

Connectivity and MPAs influence the mechanisms that support population and ecosystem resilience

1) Population buffers

2) Trophic interactions
    - predators controlling prey outbreaks (directly, indirectly - trophic cascades)
    - predators controlling community composition

3) Maintaining biodiversity
    - redundancy and complementarity
    - genetic diversity

4) Ecosystem subsidies

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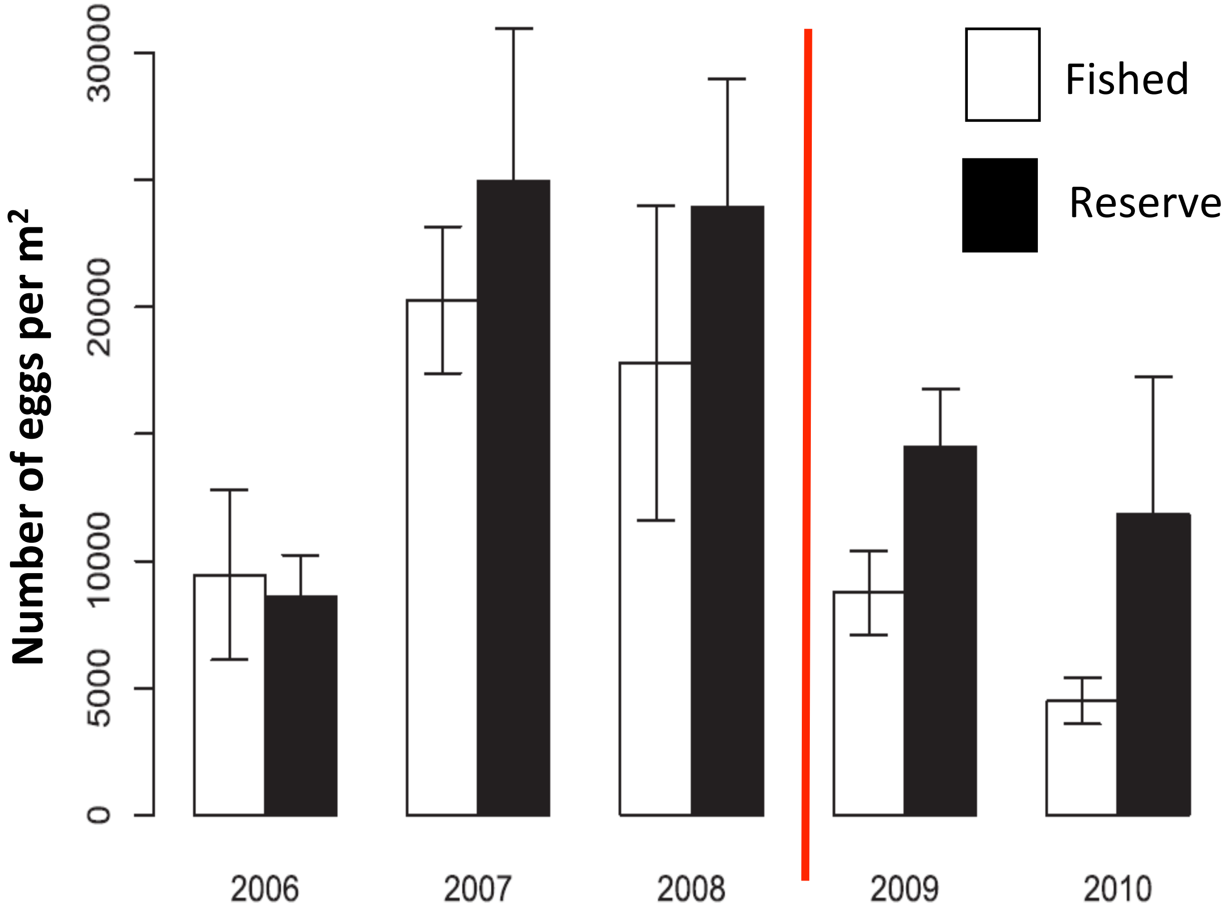
Connectivity and MPAs protect (maintain) the mechanisms that support resilient populations and ecosystems

1) Population buffers

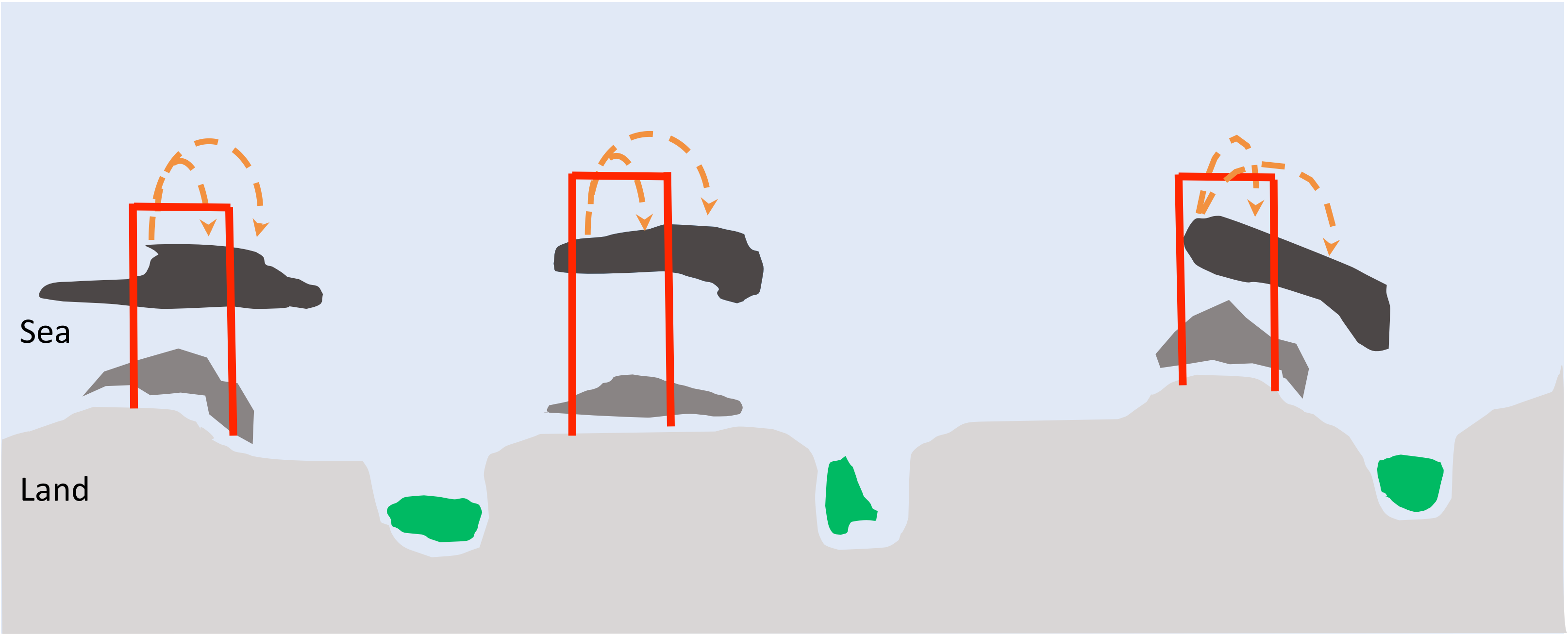
Populations with large abalone that persist in MPAs through hypoxia event rebound more quickly and contribute to recovery outside MPAs



Micheli et al. 2012 PLOS One, Rossetto et al. 2013, 2015, De Leo & Micheli 2015

Population connectivity

Size MPAs to be **self-replenishing** and to replenish populations outside MPA



Offshore ecosystems (deep rock reefs, coral reefs)

Nearshore ecosystems (kelp forests, coral reefs)

Inshore ecosystems (sea grasses, mangroves, estuaries)

Short-distance propagule dispersal within the same population

MPAs and connectivity protect (maintain) the mechanisms that support resilient populations and ecosystems

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   - redundancy and complementarity
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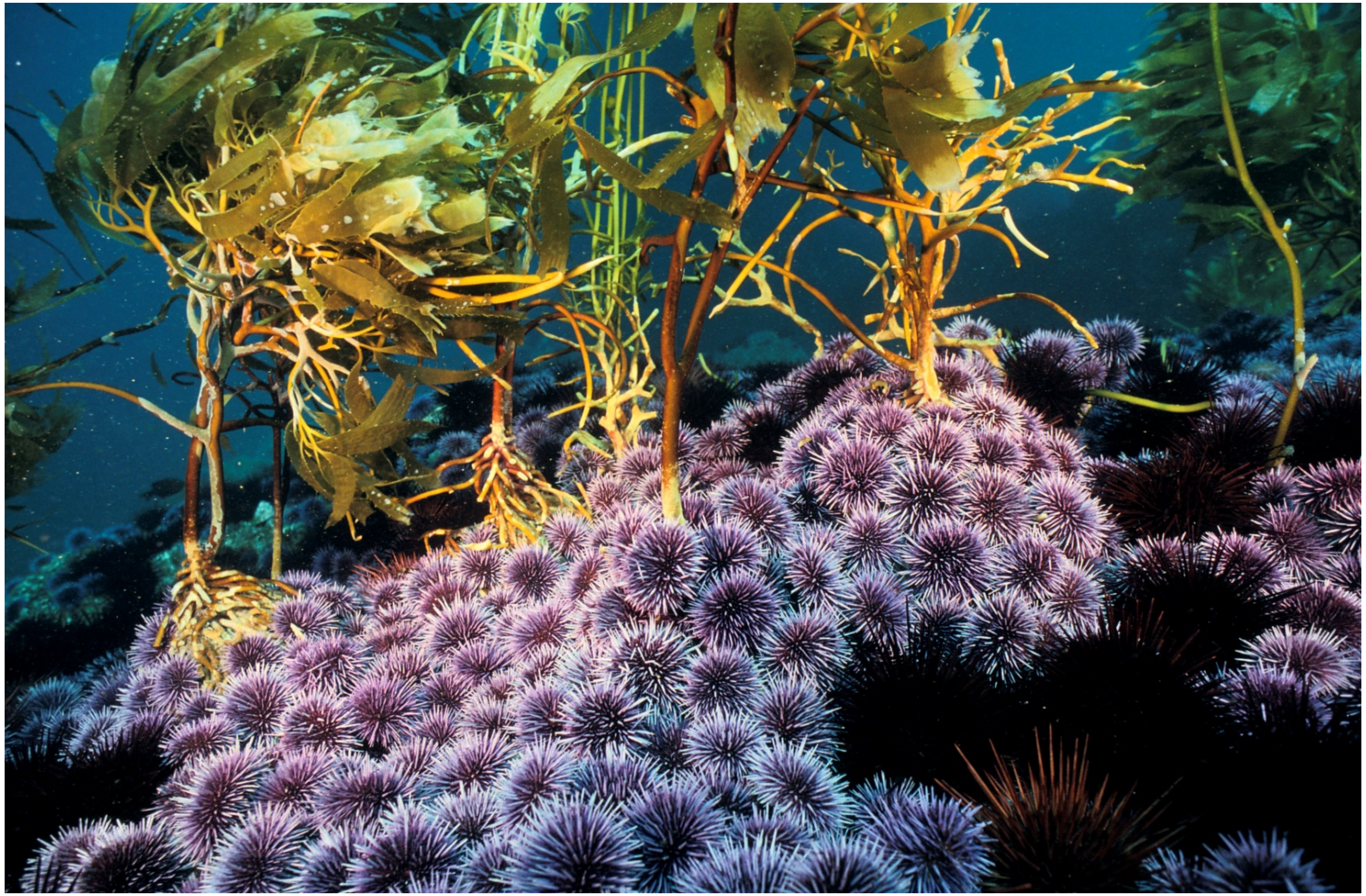
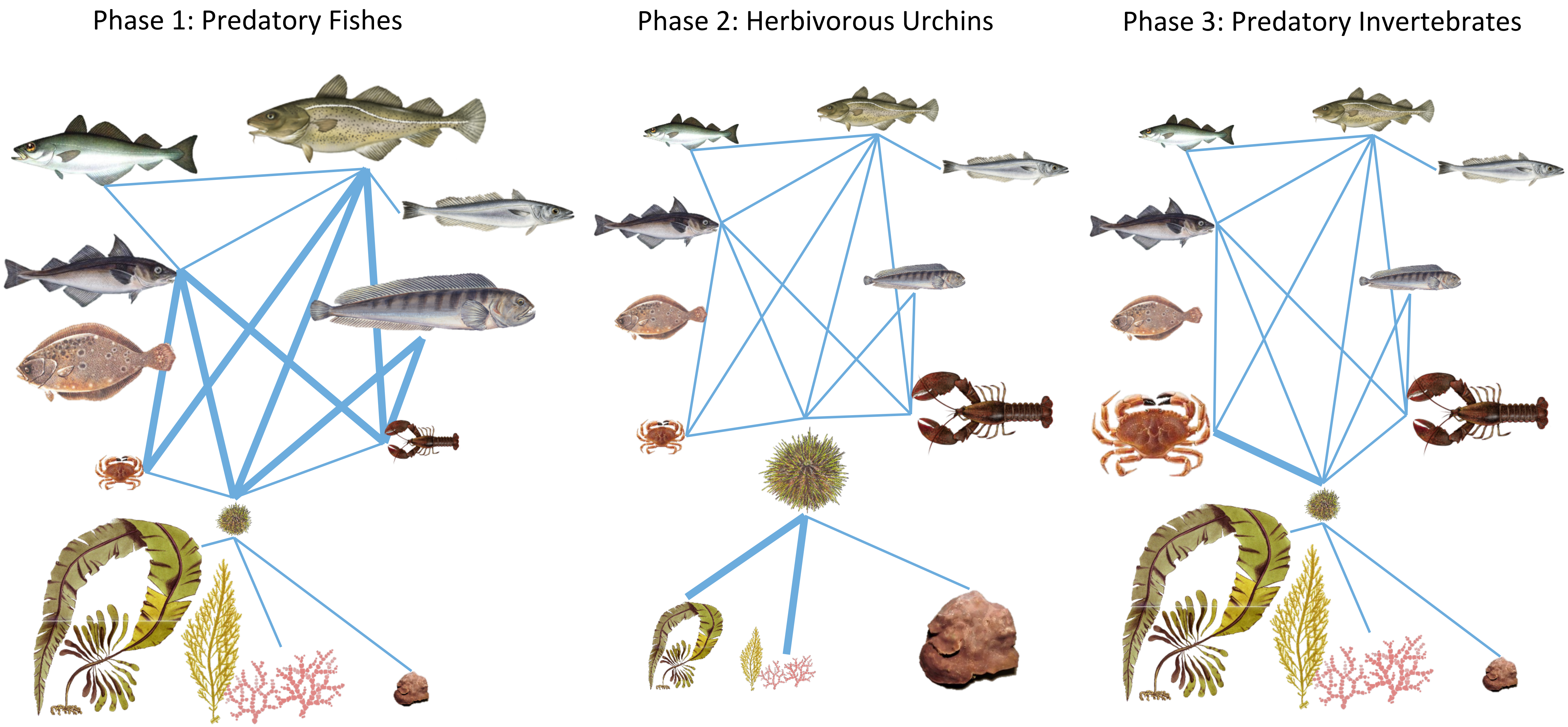
4) Ecosystem subsidies

Alternative states of kelp forest ecosystems

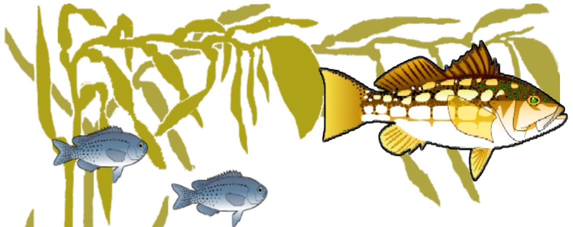


Loss of higher level predators allows system to shift to alternative stable state

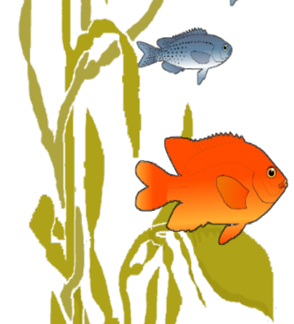


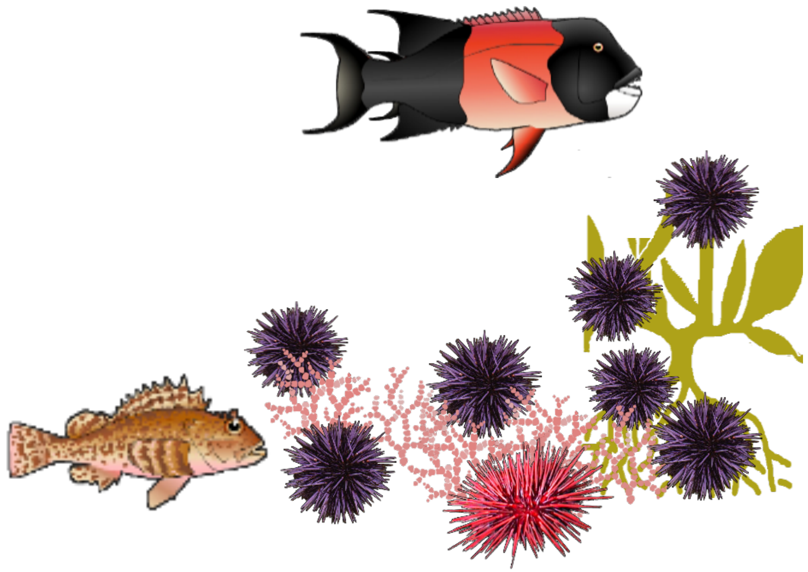
Body sizes scale to their relative abundance

Protecting “keystone” predators enhance resilience of kelp forest communities



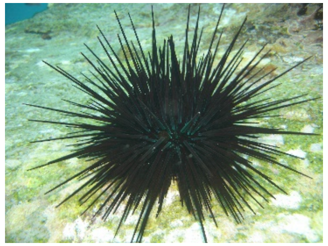
Hamilton, S.L. and J.E. Caselle. 2015. Exploitation and recovery of a sea urchin predator has implications for the resilience of southern California kelp forests.
Proceedings of the Royal Society B – Biological Sciences

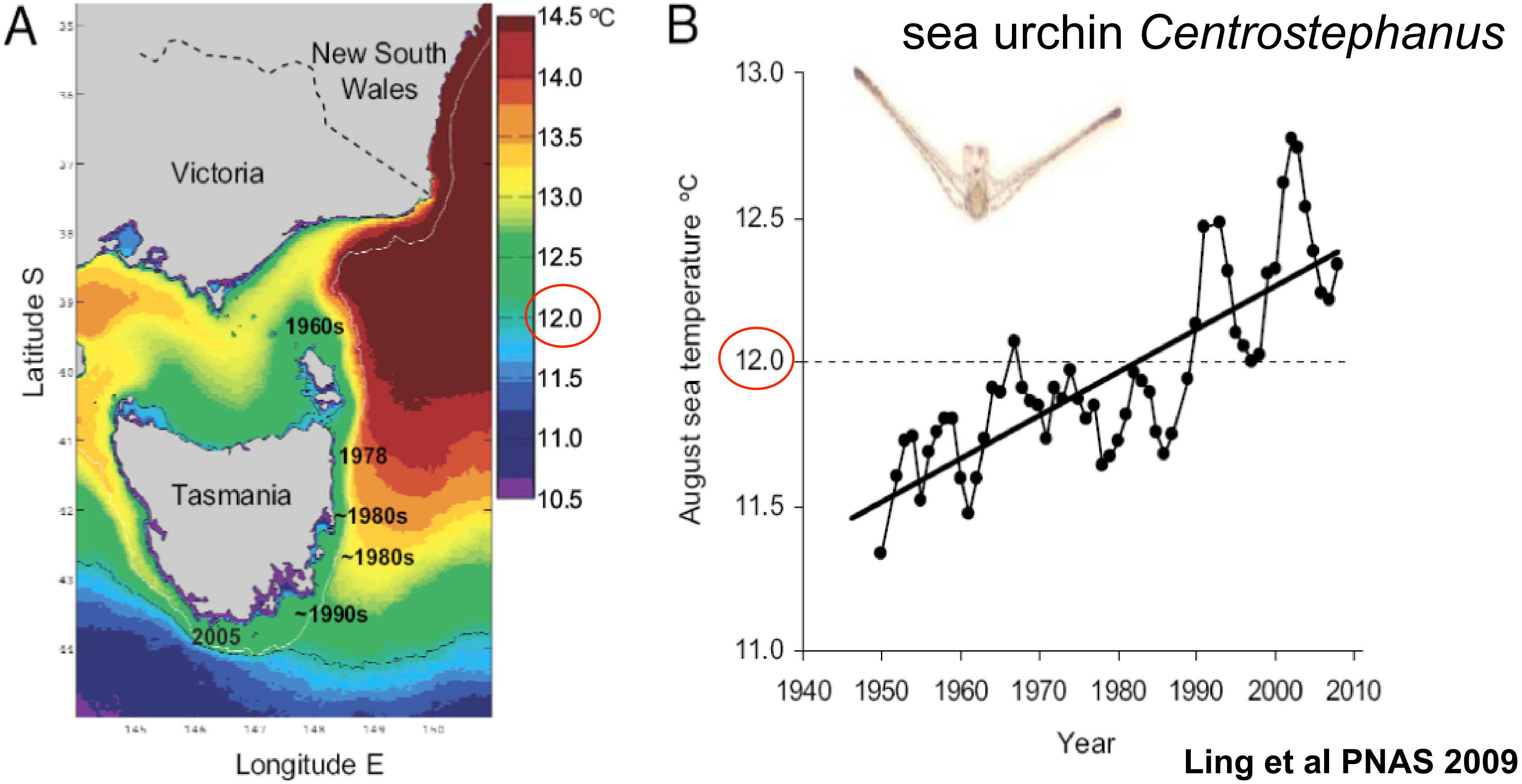




Managing for the combined effects of climate change and fishing

Lessons from down under…
Climate change facilitates invasion of sea urchin





Ling et al PNAS 2009

Marine Reserves Inform and Protect Fisheries and Ecosystems from Climate Impacts

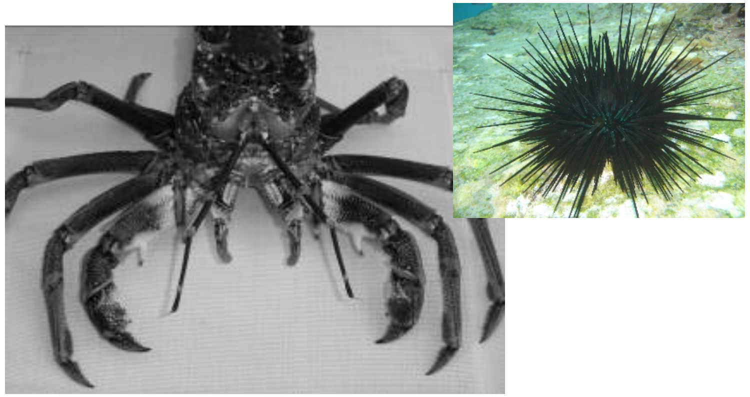
Sea urchin wipes out kelp forests that abalone fishery and biodiversity depend on

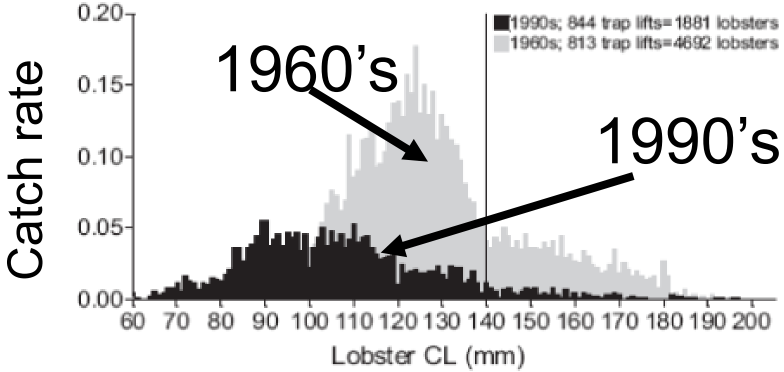
Only large lobster can eat and control invasive sea urchin

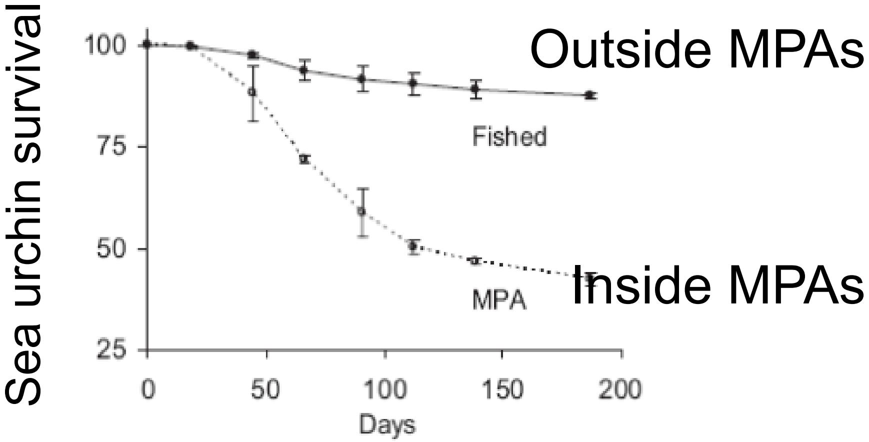
But large lobsters removed by fishery

Only in marine reserves where large lobster are protected are kelp forests protected from urchins

Large lobsters critical to resilience of kelp forest ecosystems

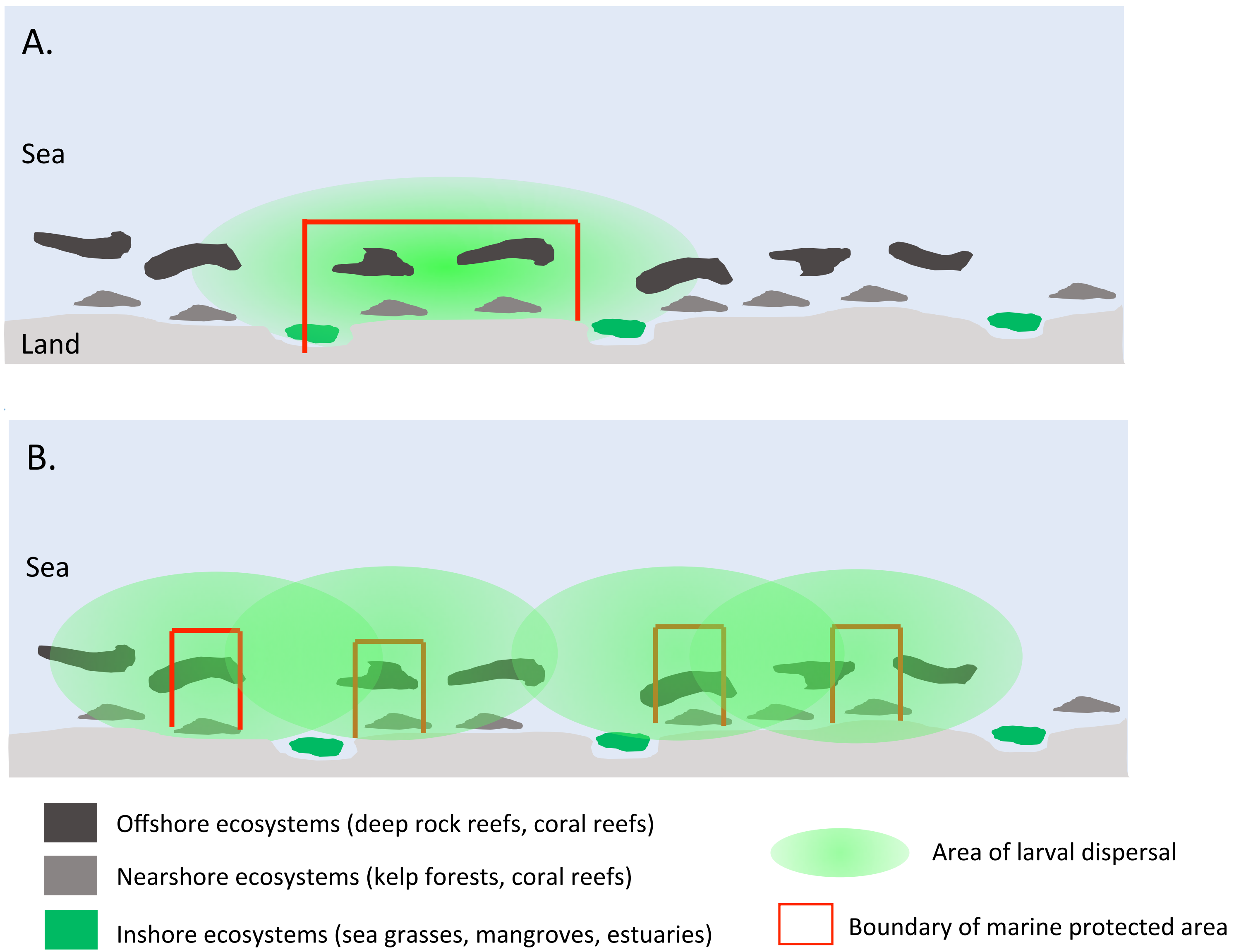






Ling et al PNAS 2009

Multiple smaller MPAs contribute to greater area or replenishment of keystone species with longer larval dispersal



MPAs and connectivity protect (maintain) the mechanisms that support resilient populations and ecosystems

1) Population buffers

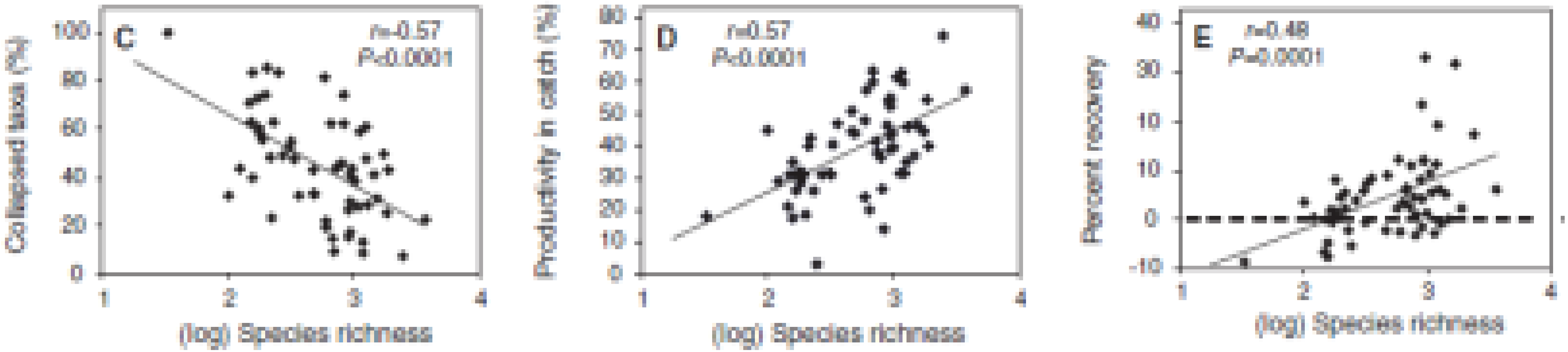
2) Trophic interactions
   - predators controlling prey outbreaks (directly, indirectly - trophic cascades)
   - predators controlling community composition

3) Maintaining biodiversity
   - redundancy and complementarity
   - genetic diversity

4) Ecosystem subsidies

MPAs and connectivity protect (maintain) the mechanisms that support resilient populations and ecosystems

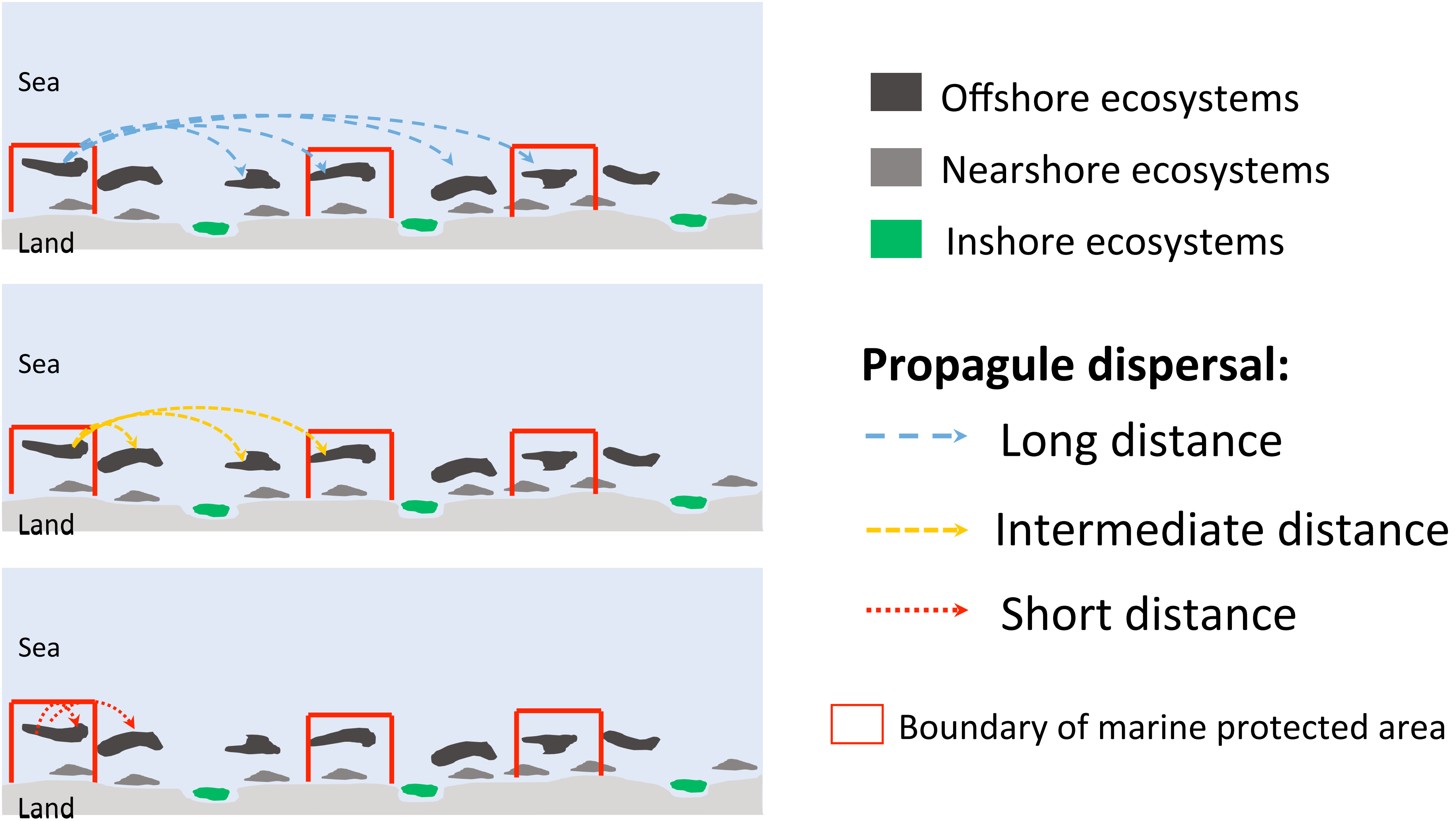
Biodiversity enhances fisheries performance



B. Worm et al., Impacts of biodiversity loss on ocean ecosystem services Science 2006

3) Maintaining biodiversity

Replenishment of multiple species between communities - metacommunities



Size and spacing of MPAs influences the diversity of species

MPAs and connectivity protect (maintain) the mechanisms that support resilient populations and ecosystems

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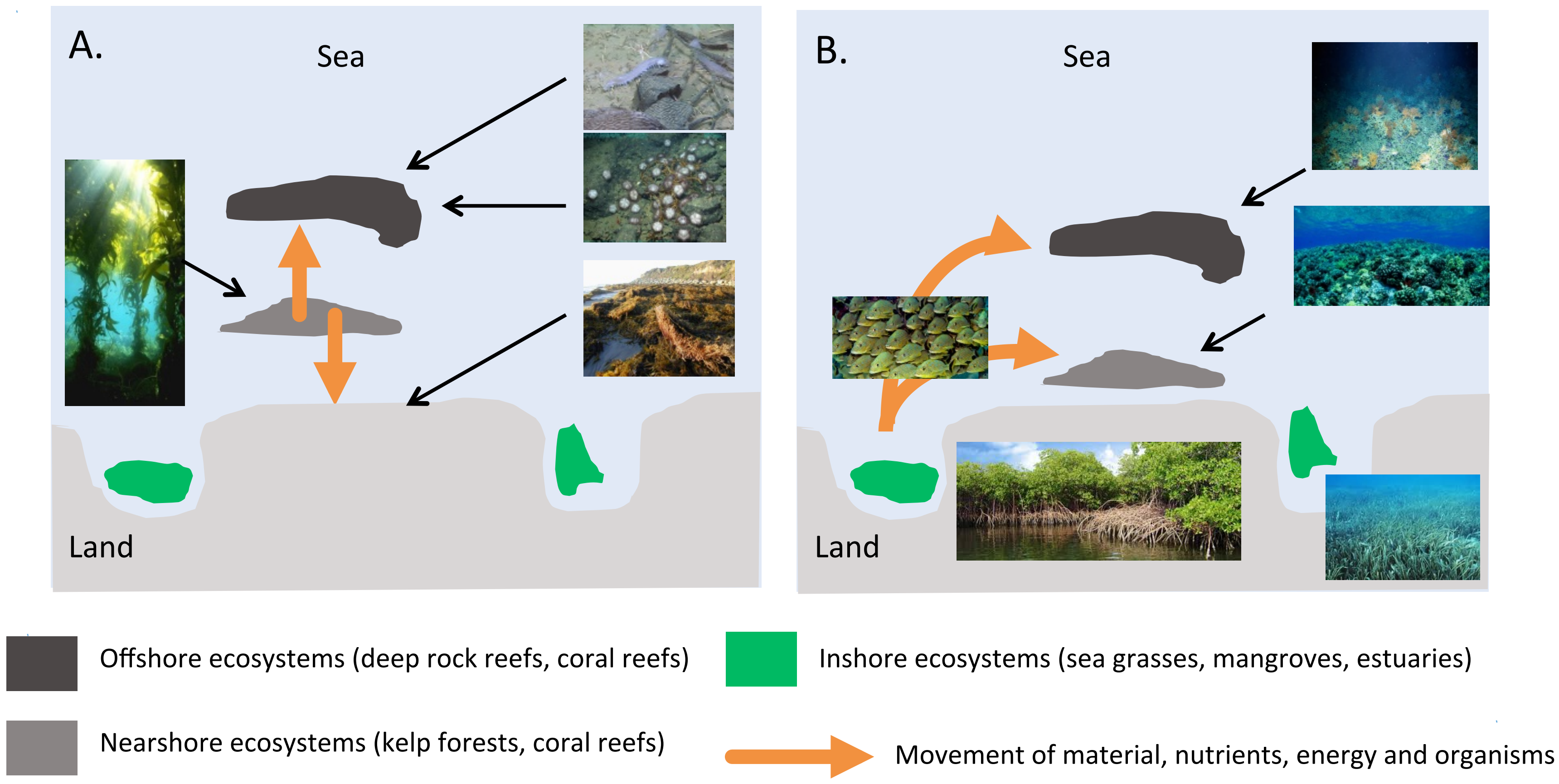
The movement of nutrients, materials and organisms between ecosystems



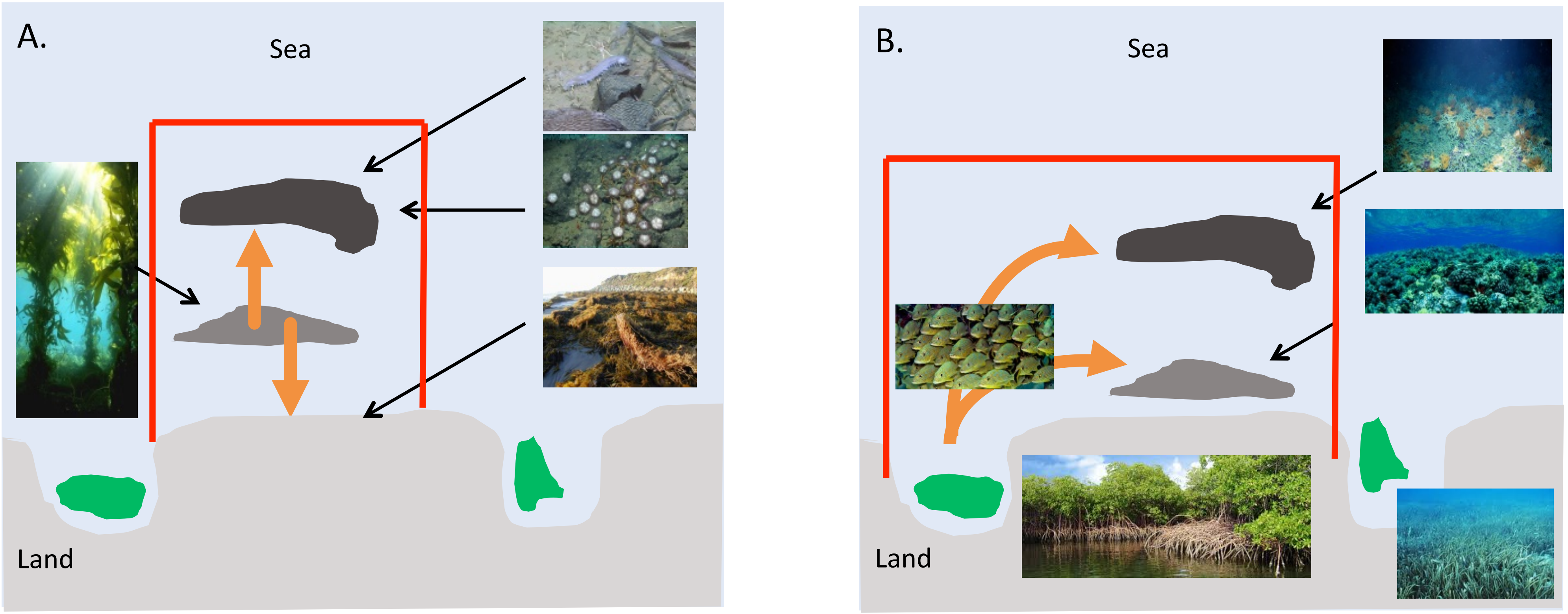
Proximity of nursery habitats determines rates of replenishment

Replenishment of herbivorous fishes on coral reefs facilitates ecosystem recovery

Neglekerken et al 2002 MEPS, Olds et al. 2012 Conservation Letters, Adam et al 2011 PLoS ONE, Olds et al 2012 Jor Applied Ecology

4) Ecosystem subsidies

Encompass multiple ecosystems within individual MPAs



Offshore ecosystems (deep rock reefs, coral reefs)

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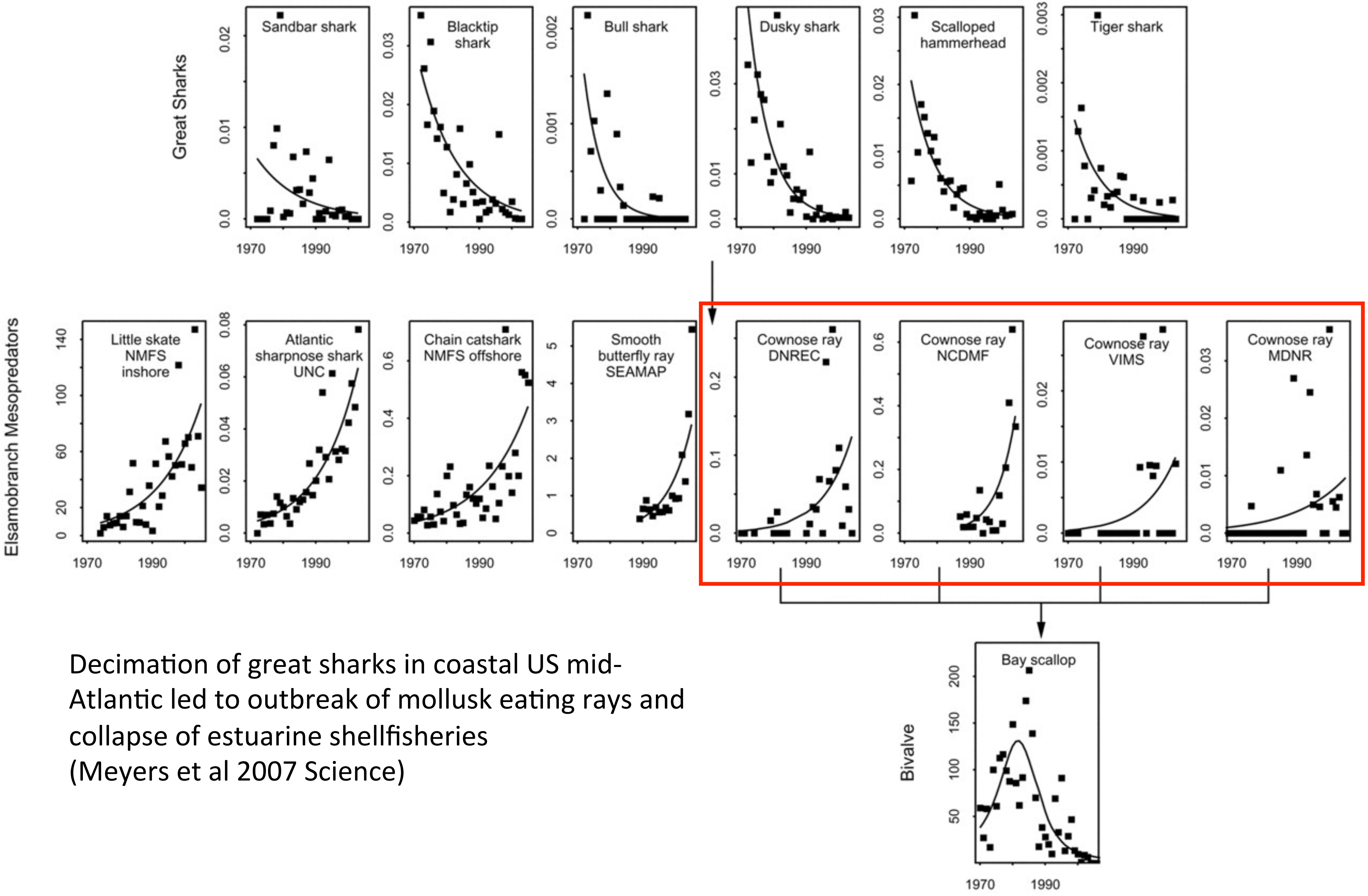
Movement of material, nutrients, energy and organisms

Conclusion

MPAs and networks of MPAs designed to protect and facilitate spatial ecological connectivity can enhance the resilience of populations and ecosystems



Decimation of great sharks in coastal US mid-Atlantic led to outbreak of mollusk eating rays and collapse of estuarine shellfisheries
(Meyers et al 2007 Science)

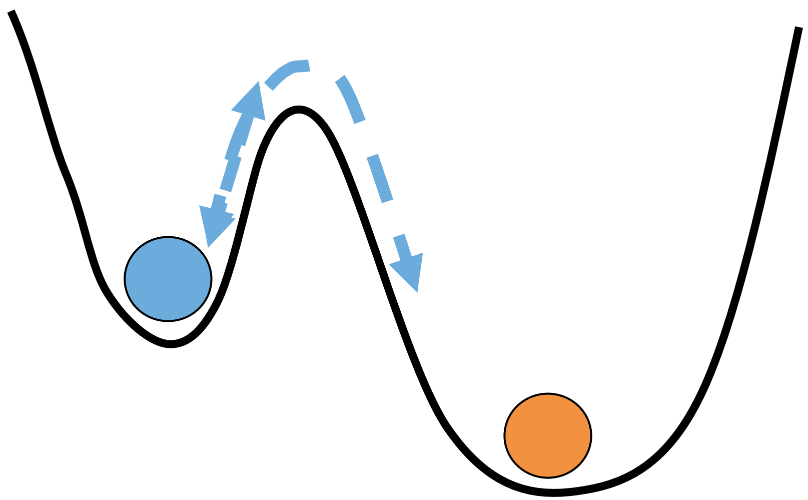
Examples: protecting mangroves and seagrass ecosystems that are nursery habitats for herbivorous fishes that eliminate algae and re-establish corals after hurricanes or coral bleaching events

The movement of young of species that depend on nearshore “nursery” ecosystems (e.g. kelp forests, mangroves, seagrass beds) to offshore ecosystems inhabited by adults (e.g., coral reefs, deep rocky reefs, deep sandy habitats) is another key form of connectivity between these ecosystems (Heck et al 2003, Mumby et al 2004, Mumby 2006, Igulu et al 2014). The relative abundance of fishes that inhabit coral reefs depends on the proximity of those reefs to mangrove and seagrass ecosystems (Figure 2.4b; e.g., Neglekerken et al 2002 Marine Ecology Progress Series, Olds et al. 2012 Conservation Letters).

These ecosystems are nurseries for herbivorous fishes that continue to replenish populations on coral reefs, where they reduce algae and facilitate the recovery of corals (e.g., Adam et al 2011 PLoS ONE, Olds et al 2012 Jor Applied Ecology).

C. S. Holling (1973): the amount of disturbance that an **ecosystem** could withstand without changing self-organized processes and structures (defined as alternative stable states)

Multiple stable states:



Species diversity
Species composition
Ecosystem productivity

Population size