Connectivity between MPAs

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Galice Hoarau

Norwegian Marine Environment

- The Norwegian coastline stretches over 2.500 km (> 83.000 km including fjords and islands)
- Territorial sea area (12 nm) = 146 831 km^2
- EEZ (200 nm) ≈ 1 million km^2
- 80% of Norway's population lives <10 km from the sea
- Essential for Norway's economy:
  - -Fisheries
  - -Aquaculture
  - -Oil & Gas (>20% GDP)

* Adjacent area in the Barents Sea is covered by a temporary agreement between Norway and The Russian Federation.

Norwegian Marine Environment

- Very diverse marine ecosystems:
  - Cold water coral reefs
  - Fjords –deep and long, anoxic/stagnant waters
  - Strong currents/tidal flows
  - Kelp forests
- Marine species:
  - •Fish & invertebrate ≈ 7500
  - •Macro-algae ≈ 500







Photos www.galice.nl

Marine Protected Areas in Norway

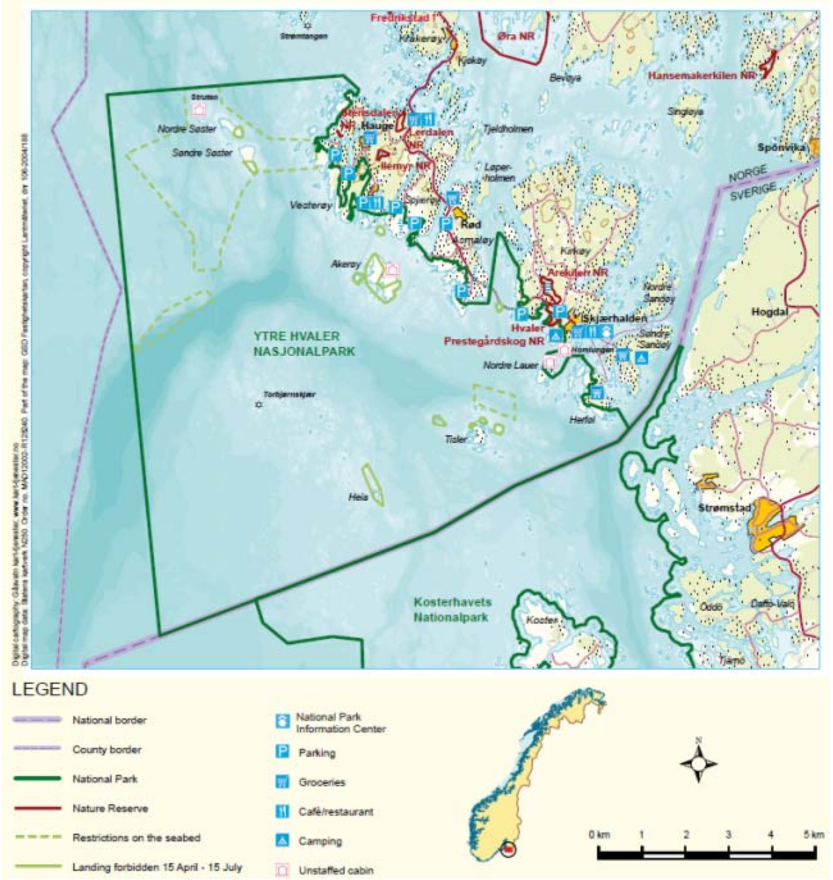
- ≈150 areas along the Norwegian coast with local-based management measures:
  - -Protection of spawning grounds
  - -Restriction by gear
  - -Prohibition against fishing for specific species
- 4 pilot MPAs established in 2006 for lobster
- 8 coral reef MPAs
- Total 2700 km2 (≈ 2%)
- 1 National Park

Coral reef MPAs

Lobster MPAs Knutsen et al 2009

Ytre Hvaler Marine National Park

- Officially opened in September 2009
- 354 km^2,14 km^2 of which are land
- Maximum depth > 470 m
- 6,000 marine species, including 220 on Norwegian and Swedish lists of endangered species
- Tisler Coral Reef: <1200 m long and 200 m broad, the largest inshore reef in Europe
- Adjacent to Kosterhavets National Park in Sweden.
- Formal cross-border collaboration
- Sweden and Norway’s first transboundary marine park



Photos Ytre Hvaler National Park

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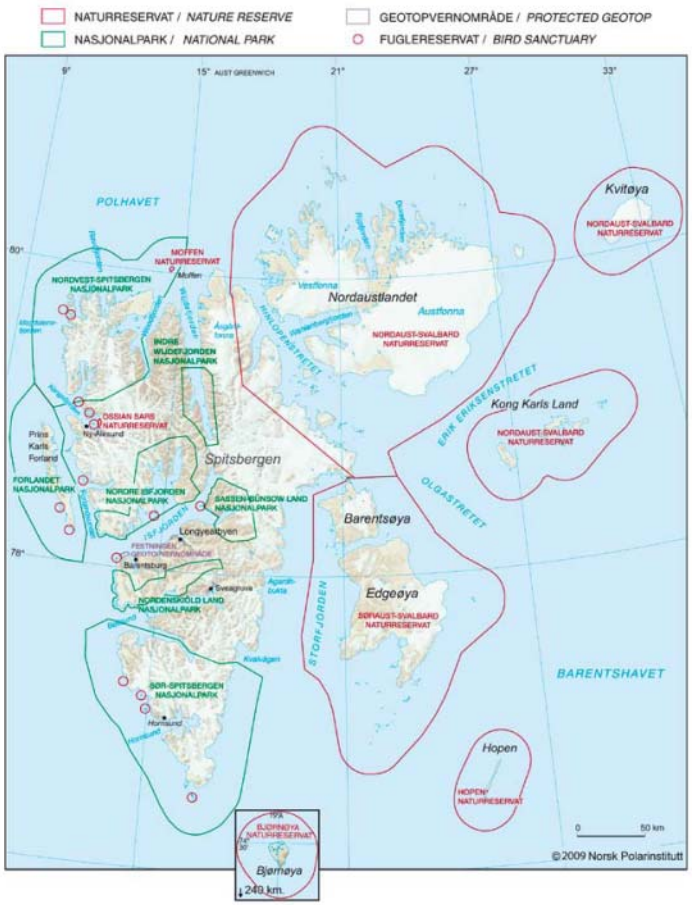
www.uin.no

Container vessel *Godafoss* grounded by Asmaløy on 17 february 2011

- Nearly 500 tons of fuel oil spilled
- Difficult cleaning due to ice
- Impact on the bird populations

Photo Greenpeace

Svalbard



- Part of the Kingdom of Norway
- Free economic zone & demilitarized zone
- 7 national parks
  - Marine ≈20,000 km^2
- 21 nature reserves
  - Marine ≈ 58,000 km^2
- In total: 86% of the territorial waters are protected (65% of the land)

Photos
www.galice.nl

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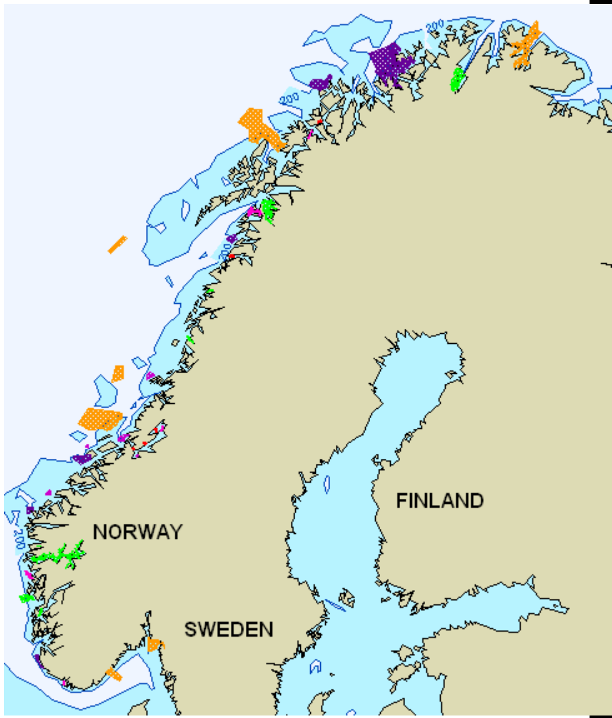
www.uin.no

National Plan for MPAs

- National goal: protect at representative selection of nature
- Strategy: protect a broad range of habitats and thereby a broad range of species
- National Advisory Committee for MPAs (Skjoldal report 2003): Proposal for **36** marine protected areas ranging in size rom 5 to 3450 km^2, **total 16,000** km^2
  - Distribution of benthic species along the coast
  - 3 biogeographic regions
    - Barent Sea
    - Norwegian Sea
    - North Sea / Skagerrak
  - 6 categories:
    - Pools (closed marine basins)
    - Fjords
    - Strong currents areas
    - Shallow water areas
    - Open coastal areas
    - Transect from coast to shelf



DIREKTORATET FOR NATURFORVALTNING

National Plan for MPAs 2011

- **17** areas are now in the establishment phase
- Hearings have started for the remaining **19** areas
- Restriction levels will depend on the specific onservation values in each candidate area
- Balance between conservation and exploitation, there should be no more restrictions than are onsidered necessary to protect the conservation alues”

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Goals of MPAs

- **Conservation:**
  - -Preservation of biodiversity
  - -Preservation of particular species
  - -Preservation of ecosystems and ecosystem services
- Fisheries management

Goals of MPAs

- Conservation
- **Fisheries management**
  - Prevent the collapse of overexploited stocks
  - Increase the size of the catchable stock

Matching MPAs Design and Objectives

Conservation:

-Preservation of biodiversity
-Preservation of particular species
-Preservation of ecosystems and ecosystem services

Biodiversity representation
Genetic diversity
Self-sustaining populations

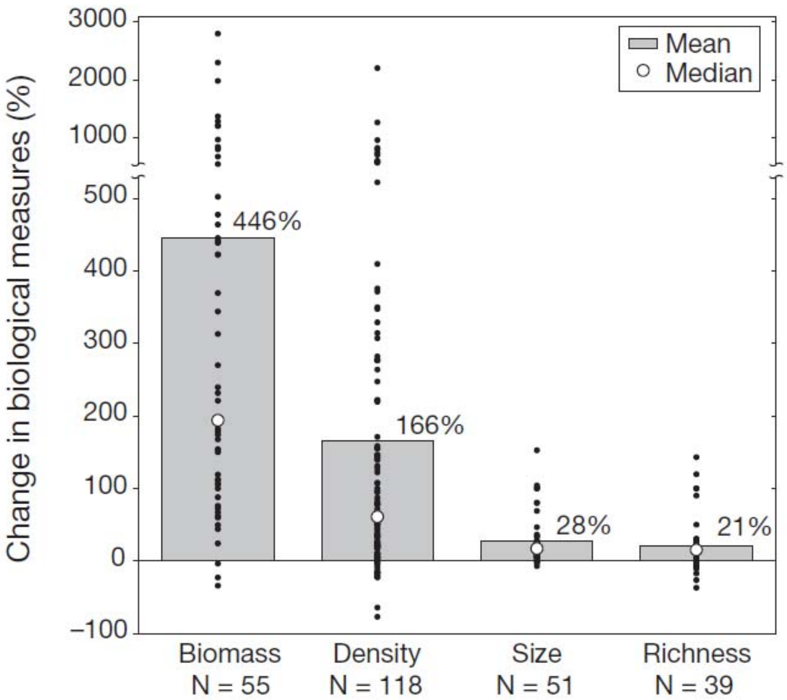
Fisheries management

- Prevent the collapse of overexploited stocks
- Increase the size of the catchable stock

Export of large fishes
Export of larvae

Halpern & Warner 2003 *Proc. R. Soc. Lond. B*

Single Reserve



- Majority of the world MPAs are single reserves
- Locations mostly based on non biological factors
- Only a very small fraction of the ocean is protected
- Large benefit mostly within the reserves

    -Biomass

    -Density

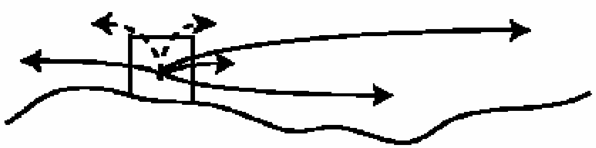
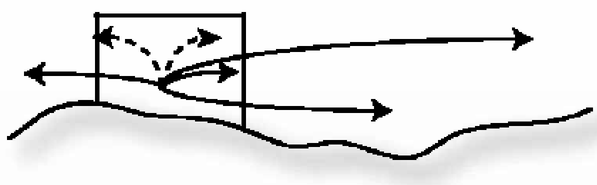
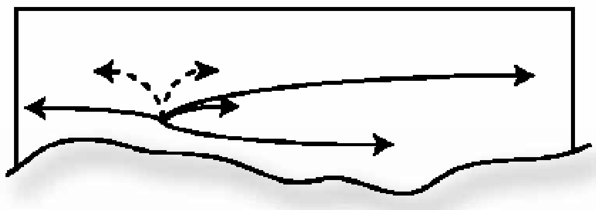
    -Size

    -Diversity

Lester et al 2009 *Mar. Ecol. Prog. Ser.*

Single reserve

Size *vs.* dispersal

	conservation	small fishery	commercial fishery	overall
	reserve not self-sustaining; most species lost	high periph-to-area ratio but unsustainable	small effect on recruitment	too much loss out of reserve; minimal effect on fisheries
	reserve moderately self-sustaining; some species lost	adequate periph-to-area ratio, with some individuals retained	significant source of recruits to fished areas; moderate reduction of fishing grounds	good balance of benefits for all stake-holders
	reserve completely self-sustaining; all species retained	low periph-to-area ratio; relatively small amounts of spillover	little recruitment outside reserve; severe reduction of fishing grounds	little export function

Halpern & Warner 2003 *Proc. R. Soc. Lond. B*

Weakness of single reserve

- For most marine species, individual MPAs have a minor conservation benefit for the species as a whole
- To provide significant conservation benefit they must be scaled up:

  -Increase the size dramatically

  -Network of MPAs

Networks as imperatives for MPAs

WORLD SUMMIT ON SUSTAINABLE DEVELOPMENT JOHANNESBURG 2002

…. the establishment of marine protected areas consistent with international law and based on scientific information, including representative **networks** by 2012

NATURA 2000

…. complete, designate, finance and ensure effective, management of the Natura 2000 **network** by 2010 (2012 for marine sites)

OSPAR COMMISSION

Protecting and conserving the North-East Atlantic and its resources

….. establishing an ecologically coherent **network** of well-managed MPAs in the North-East Atlantic by 2010

Draft Marine Bill

April 2008

…. establishing a well-managed and ecologically coherent **network** of Marine Protected Areas (MPAs) by 2012 (England & Wales)

Network of MPAs

Increased focus on networks of MPAs

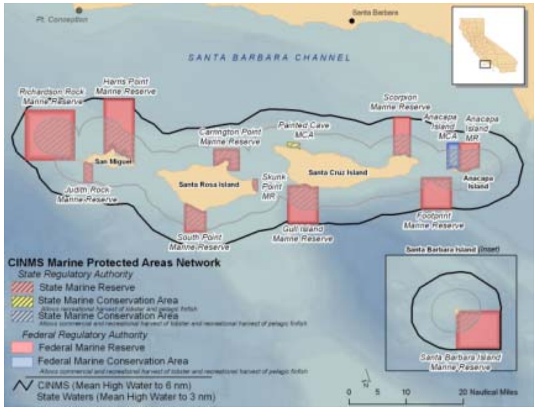
Advantage of networks:

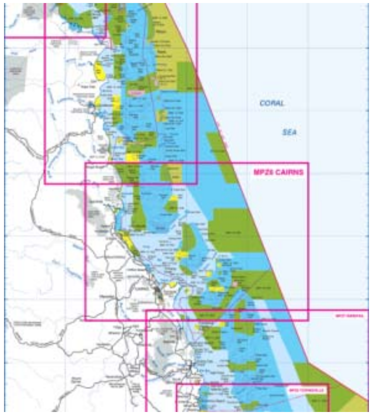
- -Synergistic effect
- -Protection of broader variety of habitat types
- -Facilitated connectivity among sites to sustain threatened populations
- -Reduce/Eliminate cost to fisheries
- -Facilitate both conservation and fisheries goals

Two successful networks of marine reserves:

- The Channel Islands Marine Reserve Network, created in 2002

- The Great Barrier Reef Marine Reserve Network, established in 2003

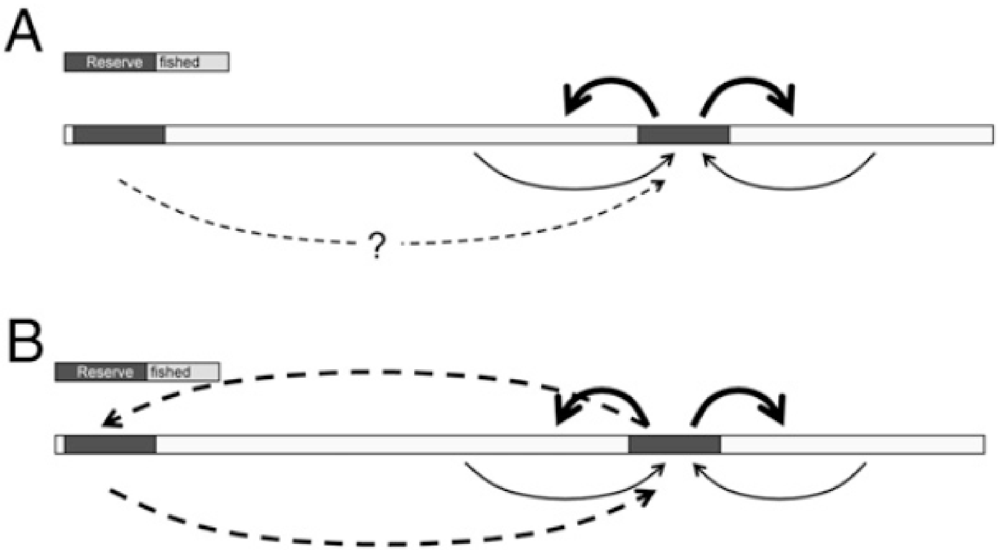




Success of network depends on size, spacing and location -> **connectivity**

Persistence in a MPA network

- Self-persistence of local populations
- Persistence depending on connectivity
- Demographic synergy



Gaines et al 2010 *PNAS*

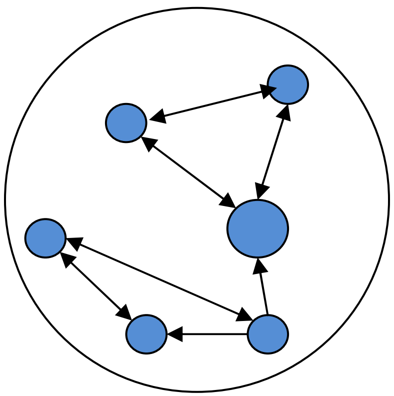
Connectivity

- "The extent to which populations in different parts of a species range are linked by exchange of larvae, recruits, juveniles, or adults"
- A network of MPAs should maximize connectivity between individual MPAs to ensure the protection of ecological functionality and productivity
- Connectivity and ecological linkages include:
    - -Connections of linked habitats
    - -Connections through larval dispersal between and within MPAs
    - -Regular settlement of larvae from one MPA to another MPA
    - -Adults movements within, between and outside of MPAs
- Importance of a system-wide approach in the design of MPA and MPA networks:
    - -Patterns of connectivity within and among ecosystems
    - -Connectivity between two populations

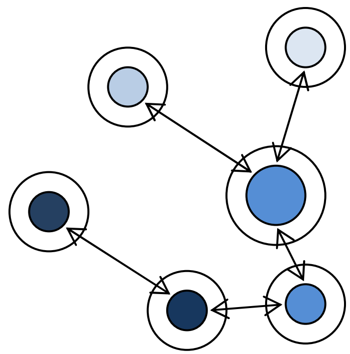
Palumbi 2003 *Ecological Applications*
Jones et al 2007 *Oceanography*

Structure of Marine Population

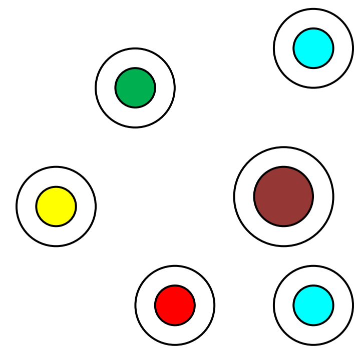
Single (patchy or continuous) population



discrete populations



isolated populations

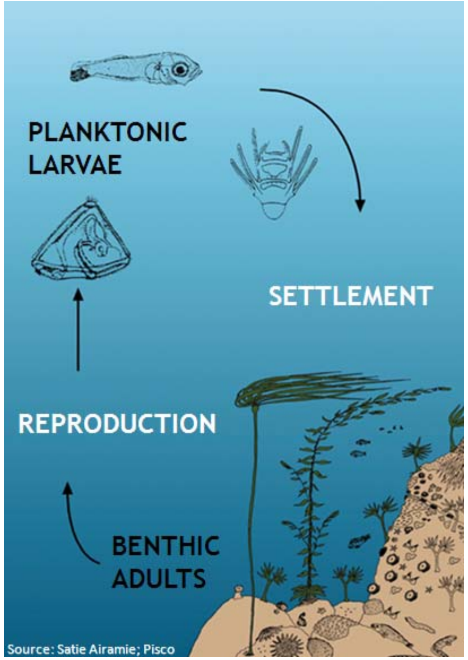


High (open) ⟷ **Low (closed)**

Population Connectivity

Structure of Marine Populations

- Many marine species have bipartite life histories:
  - Restricted movement of adults
  - Early life history stages (e.g. eggs and larvae) can disperse wide distances
  - Larvae are essentially planktonic
- But marine species can have:
  - Long distance dispersal of adults
  - No or very short planktonic phase



Structure of Marine Populations

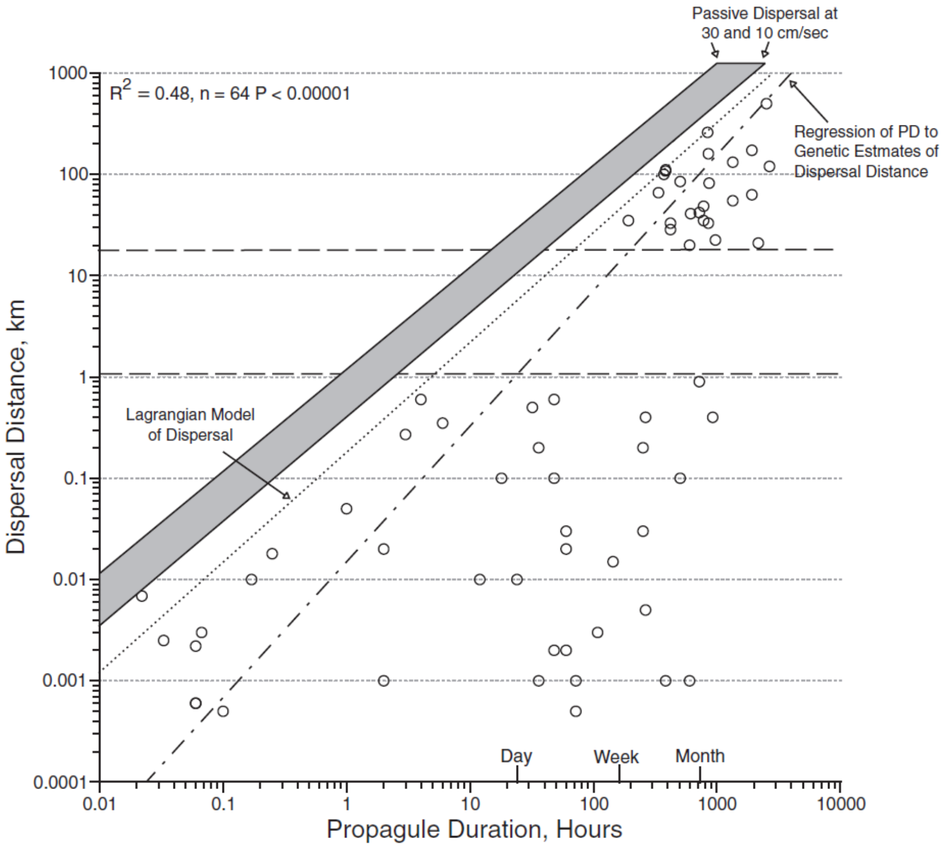
- Paradigm - Larval dispersal connects local populations over large distances

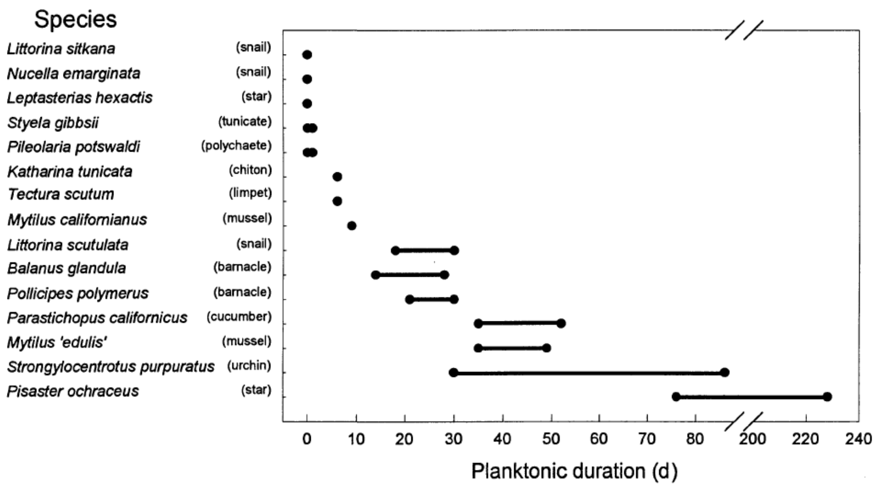
  → **Marine populations are open**

- **BUT** more and more evidence show that (some) marine populations are more closed than originally thought

Assessing Connectivity

1. Larval duration & dispersal distance





Shanks 2009 *Biol. Bull.*
Allison et al 1998 *Ecological Applications*

- Can pelagic larval duration predict dispersal distance?
- Sort of …

  -short pelagic phase ↔short distance

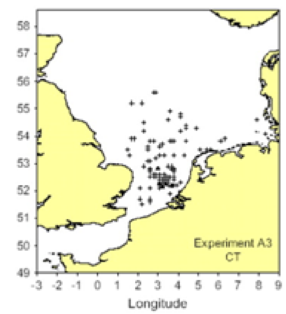
  -long pelagic phase ↔long distance

  but **many discrepancies**
- **not only passive**

Assessing connectivity
2. Tagging

• Tagging of adults

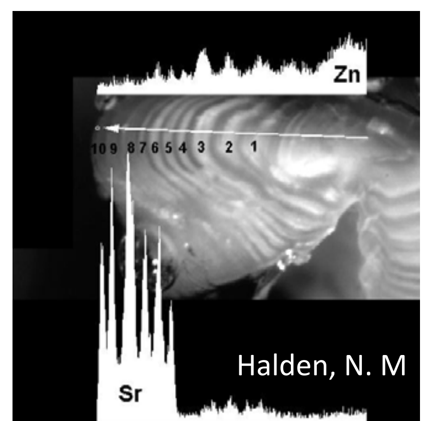
- Simple mark/recapture
- Sophisticated tags, GPS, data logger (DST)
- Does not integrate a reproductive component (feeding vs. spawning migration…)



Bolle et al 2005 *ICES J. Mar. Sci.*

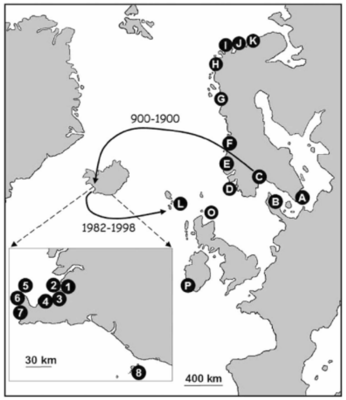
• Chemical / environmental tags

-Otoliths and stratoliths micro-chemistry
-Both adults and larvae



Assessing connectivity
3. Direct genetic method – "DNA tagging"

- Conceptually similar to physical/environmental tags
- Focus on assignment of individuals to populations of origin or to specific parents
- Use variable molecular markers to calculate the probability that a given individual originated from a particular population



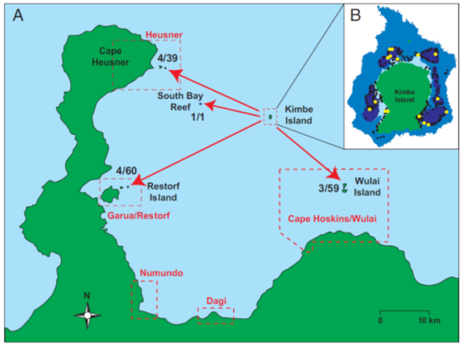
- Assignment methods can be use to infer immigration rates

  -Most effective when the connectivity is low (high genetic structure), can be a problem for many marine species

  -Most success in tracing source of invasive species

- Parentage analysis can be used to infer larval connectivity

  -good performance in high gene flow condition but incomplete sampling of potential parents is a major drawback



Hedgecock et al 2007 *Oceanography*
Coyer et al 2006 *Eur. J. Phyc.*
Planes et al 2009 *PNAS*
Saenz-Aqudelo et al 2009 *Mol. Ecol.*

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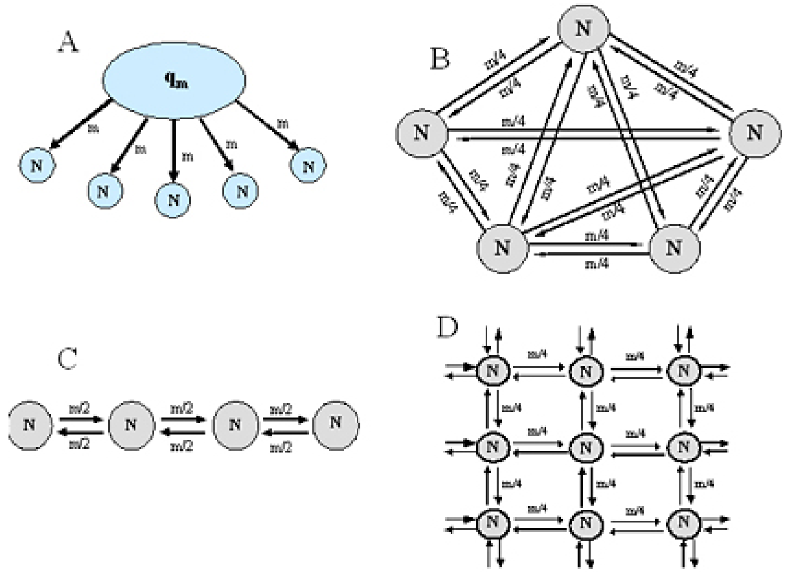
Assessing connectivity
4. Indirect genetic method

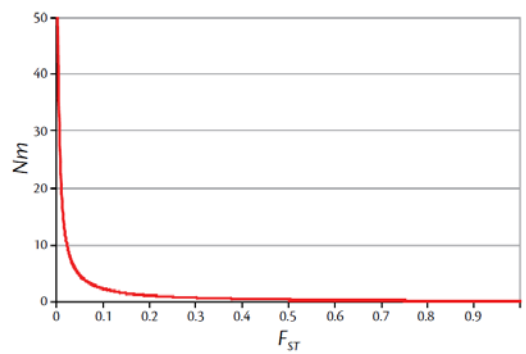
- Estimation of gene flow from genetic differences among population
- Differentiation among population: F_{st}
    - -standardized variance in allele frequencies among population
    - -$0 \leq F_{st} \leq 1$
- Estimates of dispersal rely on theoretical models of population structure



Assessing connectivity

Drawbacks of Indirect genetic method

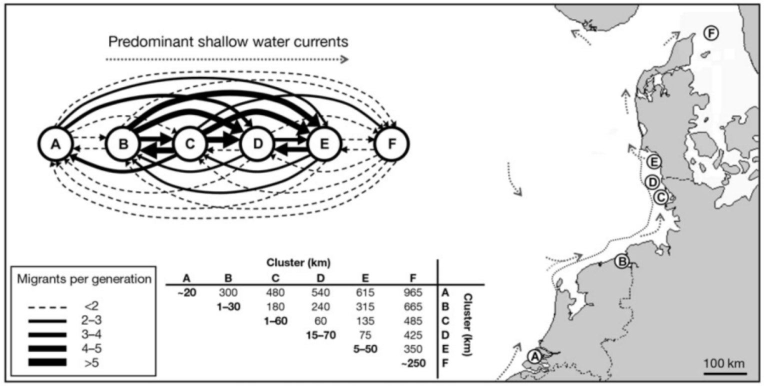
• Estimation of migration become increasingly inaccurate at low population differentiation → Moderate gene flow can be indistinguishable from random mating



Hedgecock et al 2007 *Oceanography*

• Difficulties to distinguish evolutionary from contemporary gene flow

• Development of new analytical tools based on coalescent theory



Cluster (km)	A	B	C	D	E	F
A	~20	300	480	540	615	965
B		1–30	180	240	315	665
C			1–60	60	135	485
D				15–70	75	425
E					5–50	350
F						~250

Ferber et al 2008 *MEPS*

Relevant Temporal Scale

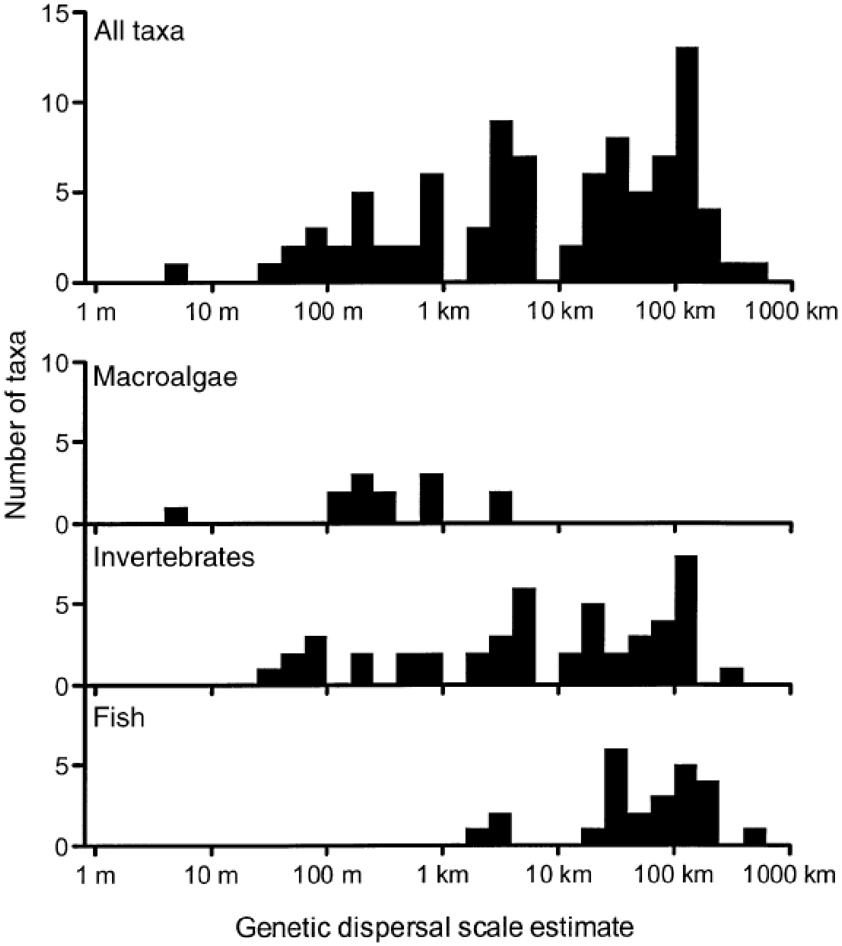
• Direct and indirect methods estimate connectivity on opposite ends of a temporal spectrum:

    -indirect genetic methods integrate connectivity over evolutionary time frame

    -direct methods give a "snapshot" of connectivity

• Biologically relevant time frames (ecological/demographic) arein between but escape both methods

Variability of Dispersal Distance



Kinlan & Gaines 2003 *Ecology*

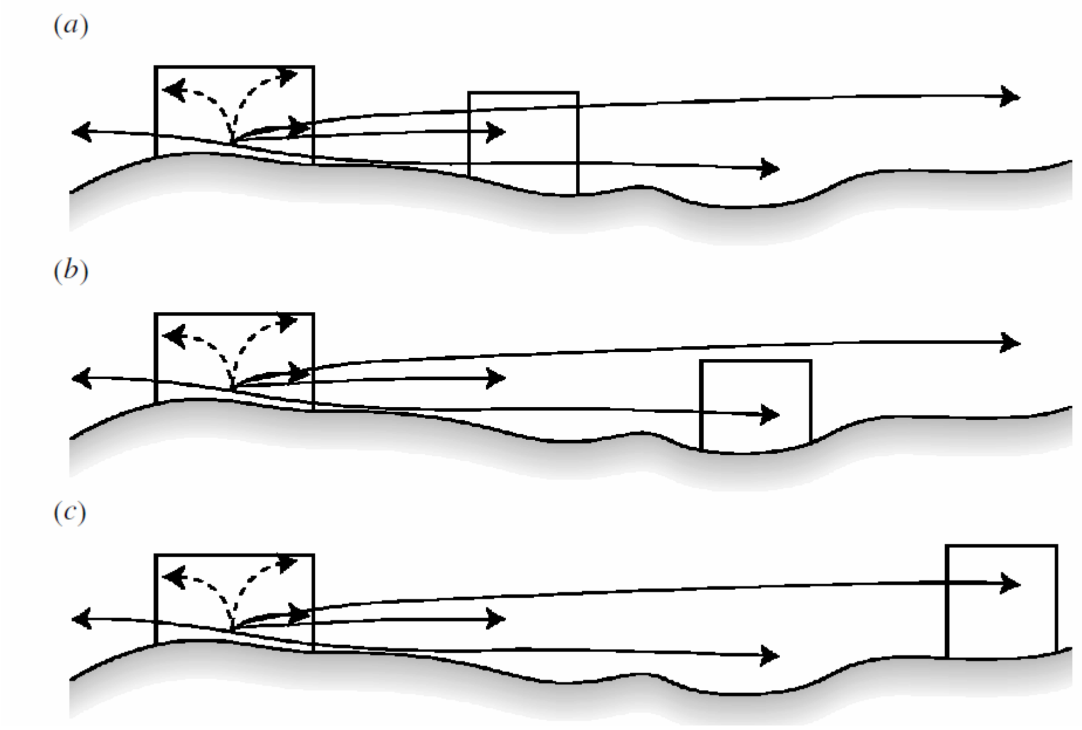
TABLE 2 Approximate adult and larval neighborhood sizes for a variety of marine life history groups[a]

Scale (km)	Adult	Larval
>1000s	Large migratory species	Intermittent gene flow, many species
100s–1000s	Large pelagic fish	Some fish
10s–100s	Most benthic fish Smaller pelagic fish	Most fish Most invertebrates
1–10s	Small benthic fish Many benthic invertebrates	Algal spores Planktonic direct developers
<1	Sessile species Species with highly specialized habitat needs	Benthic direct developers

Palumbi 2004 *Annu. Rev. Environ. Resour.*

Connectivity and MPAs Spacing

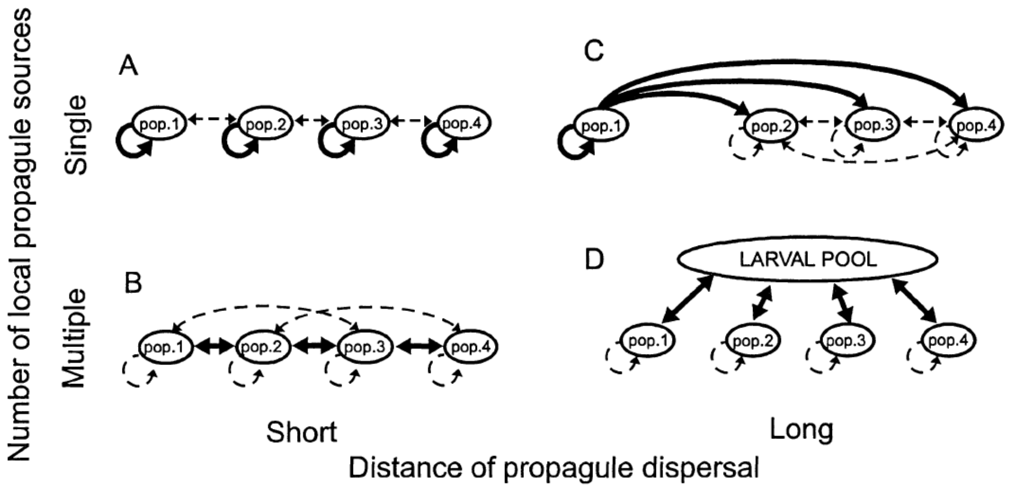
Variable Spacing

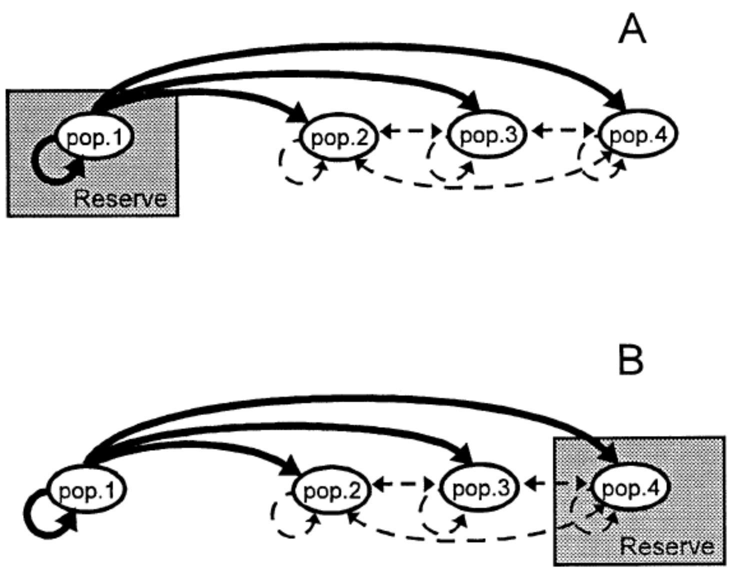


Halpern & Warner 2003 *Proc. R. Soc. Lond. B*

Connectivity and MPAs Locations

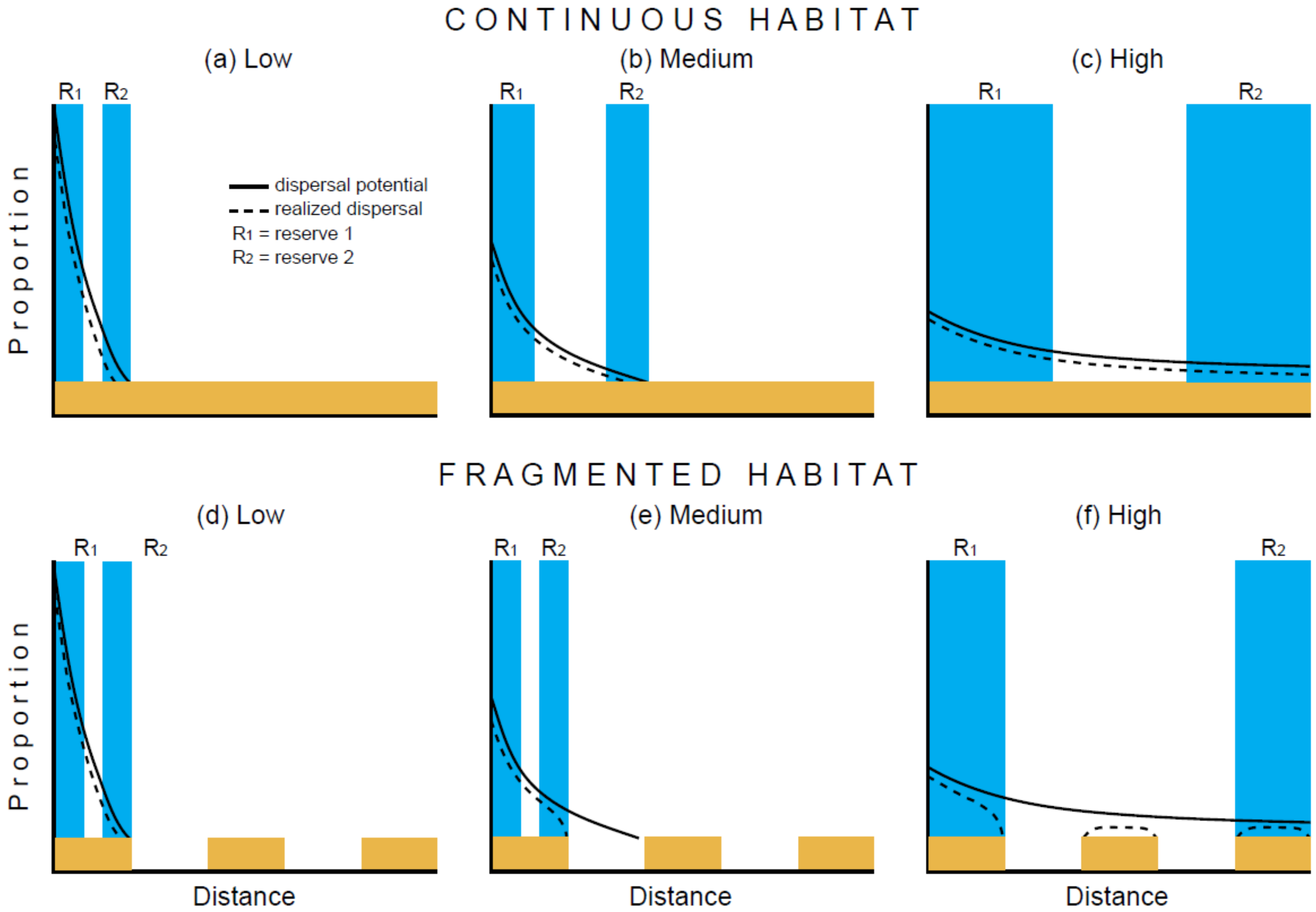
Source – Sink populations





Allison et al 1998 *Ecological Applications*

Connectivity and MPAs Locations
Habitat Fragmentation



Jones et al 2007 *Oceanography*

Connectivity and Resilience to Environmental Changes

- High connectivity can diminish the potential for local adaptation
- BUT connectivity insure the spread of successful/resilient genotype
- Without connectivity populations in the southern range of a species and the local adaptations may become lost in case of a range shift due to global warming

Conclusion

- Connectivity is an essential parameter for MPAs and MPAs network
- Marine species show a broad range of dispersal distances
- High connectivity is common but not the rule
- Accessing connectivity in marine species is still a major challenge
- Multidisciplinary approach combining physical oceanography, larval ecology, tags and genetics are necessary
- MPAs size and spacing… a difficult compromise:

    -moderate size 10s-100s km^2

    -moderate and variable spacing 10s-100s km