Lecture 10: Metapopulation dynamics

I. Introduction

A. Objectives
1. Introduce basic concepts related to metapopulations
2. Summarize methods and empirical evidence related to fish metapopulations
3. Discuss management implications of metapopulation structure

B. Background and definitions
1. Population = individuals of a single species interacting and sharing the same space and gene pool

2. Meta = going beyond, transcending

3. Metapopulation = a set of populations with independent demographics that interact through occasional dispersal (ie, a population of populations)

a. more explicit treatment of effects of Emigration, Immigration (ie, dispersal) on population dynamics
- E and I often important in pop'n dynamics:
  high I can sustain pop'n if R or S are low
  high E can reduce a pop'n even if R, S are high

b. distribution, connectivity of populations across space, time
- some "populations" may be vacant at any given instant

4. Dispersal = movement of an individual from one population to another, where it affects the other population's demographics
a. a disperser both emigrates *and* immigrates

5. Dispersal is poorly understood aspect of fish ecology
a. MANY movement studies but most not focused on dispersal

b. most recaptured fish move only short distances (restricted movement paradigm)

c. interpretation of most movement data is ambiguous
- most marked fish are never recaptured
- most recapture designs cover small spatial/temporal frames

C. Patchiness in species' distributions
1. Understanding processes, patterns of species distribution, abundance central to pop'n ecology

2. Patchiness, discontinuity occur at many spatial resolutions
a. within a geographic range – due to habitat suitability, dispersal barriers
- ranges vary greatly in size, degree of dissection

b. within a drainage basin – due to habitat suitability, dispersal barriers, biotic interactions

c. within a river/lake/reef – due to habitat suitability, biotic interactions, population size

d. not all patchiness is related to metapopulations

D. Theory of island biogeography

1. Developed to explain patterns of species richness (S) on islands
a. related to island size, distance from mainland (source)

b. related to rates of extinction (Ex), colonization (Co; mediated by dispersal)

c. S: + relationship to island size, - relationship to distance from mainland

d. Co: + relationship to island size, - relationship to distance from mainland

e. Ex: - relationship to island size, + relationship to distance from mainland

2. Applicable to *any* system of habitat patches
   Reminder – population processes, persistence also affected by environmental variation

II. Types of metapopulations

A. "Classic" metapopulations
1. Original structure suggested by island biogeography

2. Pop'ns periodically wink out but are periodically re-colonized from other pop'ns

3. Nearby habitats may be more likely to be re-colonized from source

B. "Rescue" metapopulations
1. Dispersal is frequent enough to "rescue" extinction-prone pop'ns

2. Populations are less demographically independent than in a classic metapopulation

3. Extinction/colonization may be frequent but undetected

C. Non-equilibrium metapopulations
1. Patchy structure but not really a functional metapopulation

2. Historically functioned as a metapopulation but dispersal is severely impaired

3. Interim condition -- pop'ns gradually wink out until the whole metapopulation goes extinct

D. Mainland-island and source-sink metapopulations
1. Great variation in patch quality/function

2. For M-I, "mainland" patches have larger populations that provide most immigrants to "island" patches

3. For S-S, hi-quality "source" patches produce a surplus of individuals that can disperse
   to lo-quality "sink" patches, which can't demographically sustain themselves

E. Hybrids
1. Any elements of the previous idealized models can be combined to describe real life

III. Evidence for metapopulations

A. Detecting metapopulation dynamics
1. Delineate the populations themselves (i.e., describe how individuals cluster in space)
   a. far from a trivial exercise in most cases (e.g., oceanic, riverine systems)

   b. assuming we can delineate pop'ns, need to assess independence of dynamics, dispersal rates

2. Demographic studies

a. best strategy: examine M, R, E, I rates, develop models to estimate strength of interactions
b. rarely occurs because of prohibitive costs (time, $)

c. available demographic studies indicate that most species would not persist for 100 years without immigration (we assume similar importance for unstudied species)

3. Field surveys of patch occupancy
   a. examine patterns of presence/absence, compare to metapopulation predictions
      - pop'ns should persist relatively large, well connected patches (ie, non-randomly)

   b. in long-term database for southwestern US fishes in rivers and springs:
      - broadly but sparsely distributed species more likely to exhibit local extinctions
      - narrowly but compactly distributed species more likely to persist

4. Direct measures of dispersal (tagging studies)
   a. mark/recapture, radio telemetry studies reveal patterns of fish movement, including dispersal

   b. require large investment (time, effort) to detect occasional dispersal

   c. few tagging studies adopt spatial extent commensurate with true dispersal

   d. still, our best source of empirical estimates of dispersal rates
      - tagging salmon smolts as they leave natal spawning areas, then measuring rate of "straying" to other spawning areas upon return

      - small minority of movements (<10%) can have huge adaptive significance

5. Genetic methods
   a. use signatures of mutations in nuclear DNA to map spatial variation in genetic composition

   b. measure the degree to which populations are spatially structured (exhibit break points)

   c. estimate dispersal rates (number of migrants per generation) between populations

   d. estimate population size

   e. expensive ($) to analyze tissue samples

   f. need to be calibrated with empirical (field-based) estimates
      - species differ in their mutation rates
      - validate other molecular assumptions

   g. overall, best (and often only) method for examining large-scale fish movement

B. Evidence in marine fishes
   1. Open-ocean environments do not promote much population structuring
      - highly mobile epipelagic fishes (eg, tuna) unlikely to function as metapopulations

   2. Inshore (shoreline or reef) fishes more likely to exhibit metapopulations
      - many north-Atlantic stocks structured around Cape Hatteras split
        between Atlantic and Gulf Coast sides of Florida

C. Evidence in anadromous fishes
   1. Often "home" to natal spawning area, setting up a metapopulation structure
      a. functionally a metapopulation even if populations mix completely in the ocean

b. “straying” equates to dispersal
- eg, source-sink model for Chinook salmon in Sixes River, OR

D. Evidence in freshwater fishes
1. Beaver ponds in Minnesota are productive sources of migrants for adjoining stream reaches

2. Many declines in stream fishes may reflect the non-equilibrium pattern
- habitat insularization due to dams, intensive land use, pollution, etc. (eg, river redhorse)

IV. Some management implications

A. Populations are dynamic over long timeframes
1. Most will eventually crash and need re-colonizing
a. immigrants restore numerical and genetic viability

b. some “populations” of a metpopulation may be unoccupied
- underscores need for landscape-wide perspective in managing pop’ns

B. Dispersal is crucial to long-term population viability (even if it occurs only occasionally)
1. Reduced population connectivity is major consequence of industrialized landscapes
a. insularization = habitat loss + connectivity loss

b. impaired dispersal → breakdown of metapopulation structure

2. Rates and circumstances of dispersal are poorly understood
a. may affect outcomes of management actions in unexpected ways
- eg, cover-enhancement structures in streams may boost immigration, not recruitment

C. Reserves as conservation tools
1. Marine reserves established to exclude fishing
- productive recruitment “sources” to sustain stocks (via dispersal) in heavily fished “sinks”

2. Watershed reserves (Pacific Northwest salmonids) established to limit dams, timber harvest
- productive recruitment “sources” to sustain stocks (via dispersal) in intensively used “sinks”

3. Insufficient means to conserve fish populations if dispersal is severely impaired