Persistence metrics and data connections

July 23, 2018

1 Self-persistence calculation

Metric

A patch is self-persistent (Burgess et al. (2014)) if

$$LEP \times LR \geq 1, \quad (1)$$

where LEP (lifetime egg production)is the reproductive output from recruitment to death, where both recruit and the stage of offspring outputted need to be defined. LEP is calculated by:

$$LEP = \Sigma_{a=1}^{A} l(a) f(a), \quad (2)$$

where a is age, starting at age of recruitment, A is age of death, $f(a)$ is fecundity at age a, and $l(a)$ is survival from recruitment to age a. Fecundity could be considered in terms of eggs or could include some mortality and be defined in terms of larvae, juveniles, recruits, etc. LEP could have site-specific survivals and fecundities.

LR (local retention) is the fraction of larvae (or other stage) that are produced by a patch that return to settle,

$$\begin{aligned} LR &= \frac{\text{\# arrivals returning home}}{\text{output from patch}} \\ &= \frac{\text{\# recruits arriving home}}{\text{\# recruits produced by patch}} \\ &= \frac{p_{\text{dispersing home}} \times \text{\# recruits from site}}{\frac{\text{recruits}}{\text{eggs}} \times \text{\# eggs produced by site}} \end{aligned} \quad (3)$$

For this to work, the life stage considered as offspring in LEP and the life stage in LR should be the same. Basically, this is seeing whether a reproductive individual will be able to replace itself, considering its total lifetime output (and the survival of that output to a recruitment stage) and the probability of that output returning to its natal patch. Breeding females or 3.5cm

Putting this all together, for a 3.5cm recruit as the starting age and fecundity in terms of eggs, you get:

$$SP_i = LEP_{i,a_0\,=\,3.5\text{cm}} \times \frac{\text{recruits}}{\text{egg}} \times \frac{\text{recuits arriving home to patch i}}{\frac{\text{recruits}}{\text{egg}} \times \#\text{eggs produced by patch i}} \geq 1, \quad (4)$$

which simplifies to be

$$SP_i = LEP_{i,a_0\,=\,3.5\text{cm}} \times \frac{\text{recuits arriving home to patch i}}{\#\text{eggs produced by patch i}} \geq 1. \quad (5)$$

Or, could be

$$SP_i = LEP_{i,a_0\,=\,3.5\text{cm}} \times \frac{\text{recruits}}{\text{egg}} \times \frac{p_{\text{dispersing home}} \times \#\text{ recruits from site}}{\frac{\text{recruits}}{\text{egg}} \times \#\text{eggs produced by patch i}} \geq 1, \quad (6)$$

which simplifies to

$$SP_i = LEP_{i,a_0\,=\,3.5\text{cm}} \times \frac{\text{recuits}}{\text{eggs}} \times p_{\text{dispersing home}} \geq 1. \quad (7)$$

Data

- A: assuming fish are 1 when they hit 3.5cm, can use the max number of years a fish has been recaught (checking with a histogram that this a minority of fish and likely that we have caught the tail, not the majority) or a number from the literature or annual average survival multipled until proportion surviving is $<$ some threshold (1%?)

- $f(a)$: can start with an average number of eggs per female multiplied by average number of reproductive events per year from Adam's work, then can nuance with size of female (and age from Michelle's growth work or a von-Bertalanffy to estimate age from size), if necessary. Then need to to multiply by probability of surviving from egg to recruit (either here or outside the sum). Or use IPM like Will White did to get at size effects on survival and egg production.

- $l(a)$: Use survival-at-size relationship to estimate annual survival at each size (or just use an annual survival) and multiply together to get survival to each age. This is survival from first age of reproduction to the other stages or survival from some other stage to the various ages - need to make sure that is really clearly defined. Could be lifetime egg production of a breeding female, of a 3.5cm recruit, or a larvae, etc.

- #eggs produced by patch i: fecundity (either average or size-specific) multiplied by the estimated number of breeding females at a site (either total or by size)

- #recruits arriving home to patch i: KC's dispersal kernel (which is prob of dispersing a certain distance, given that you are a settled recruit) multiplied by the number of recruits arriving at that site?

  $$\text{recruits arriving home} = \#\text{ recruits from the site} \times p_{\text{dispersing w/in site}}$$

  , where $p_{\text{dispersing w/in site}}$ is the dispersal kernel integrated over the site width and represents the probability of settling within site boundaries, given that you settled somewhere, and # recruits from the site is the number of recruits that settled somewhere produced from site i. This can be calculated as

- Can estimate egg-recruit survival ($\frac{\text{recruits}}{\text{egg}}$) by getting the number of 3.5cm-sized fish (or recruit defined at a different stage - reproductive fish, reproductive female) at each patch compared to the number of eggs produced by the patch the year before. This assumes eggs only recruit to their patch, though, which is what we're trying to test here, so would want to consider these ratios at different spatial scales, like the whole population together. Need to think about this a bit more. Given the number of females out there in each patch and overall population, how many recruits do we see the next year?

- #recruits arriving home to patch i (alternate): could just use raw # of parentage matches found returning home and scale that by the estimated proportion of the site sampled (only works if we actually get some self-recruits for some of the sites, though - and would be a pretty rough estimate)

Network persistence: shortfall of SP

Metric

A patch is persistent through network persistence if it is persistent but not through self-persistence.

$$P_i = LEP_{i,a_0\,=\,3.5\text{cm}} \times \frac{\text{recuits arriving to patch i}}{\text{\#eggs produced by patch i}} \geq 1. \tag{8}$$

Assess persistence by:

$$\frac{\text{recruits}}{\text{female}} * \text{survival to breeding} \geq \text{annual mortality} * N_{\text{females}} \tag{9}$$

Or, could assess persistence in the same way as self-persistence but use all recruits coming to the site as the numerator. If it is persistent but not self-persistent, must be through network persistence (so if $P_i \geq 1$ but $SP_i < 1$).

Data

- $\frac{\text{recruits}}{\text{female}}$: LEP from stage of breeding female (rather than 3.5cm as above) multiplied by survival of eggs to recruits (either estimated from relationship or from literature)
- survival to breeding: use annual survival to estimate survival from recruitment (3.5 or whatever) to breeding female
- annual mortality for breeding females: same as used in LEP above, have from mark-recap
- N_{females}: estimated at a site by scaling up N_{captured} by prob of catching a female (could redo Lincoln-Peterson for just breeding females) and proportion of site sampled

Network persistence: demographic connectivity matrix

A group of patches are network persistent if the largest eigenvalue of the demographic connectivity matrix (C) is > 1 (Burgess et al. (2014); Garavelli et al. (2018))

$$C_{ij} = LEP_i \times p_{ij}, \tag{10}$$

where LEP_i is the lifetime egg production at patch i and p_{ij} is the probability of a recruit dispersing from patch i to patch j.

$$\text{realized connectivity matrix} = \text{reproductive output (in terms of "recruits")} \times \text{dispersal prob (for "recru} \tag{11}$$

Equations for presentation

$$SP = LEP \times LR \geq 1 \tag{12}$$

$$LEP = \Sigma_a^A l(a) f(a) \tag{13}$$

$$LR = \frac{\text{\# arrivals returning home}}{\text{output from patch}} \tag{14}$$

$$SP_i = LEP_i \times \frac{\text{recuits arriving home to patch i}}{\text{\#eggs produced by patch i}} \geq 1 \tag{15}$$

$$NP_i = LEP_i \times \frac{\text{recuits arriving to patch i}}{\text{\#eggs produced by patch i}} \geq 1 \tag{16}$$

$$C_{ij} = LEP_i \times p_{ij} \tag{17}$$

References

Scott C Burgess, Kerry J Nickols, Chris D Griesemer, Lewis AK Barnett, Allison G Dedrick, Erin V Satterthwaite, Lauren Yamane, Steven G Morgan, J Wilson White, and Louis W Botsford. Beyond connectivity: how empirical methods can quantify population persistence to improve marine protected-area design. *Ecological Applications*, 24(2):257–270, 2014.

Lysel Garavelli, J. Wilson White, Iliana Chollett, and Laurent Marcel Chérubin. Population models reveal unexpected patterns of local persistence despite widespread larval dispersal in a highly exploited species. *Conservation Letters*, page e12567, 2018.