

Populations

Biologia della Conservazione 25/26

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What is a population?

- ▶ The traditional definition of a population is:
 - ▶ All individuals of the same species coexisting at the same time and in the same geographic area (Dyke & Lamb, 2020)
- ▶ This definition is strictly biological, but it could be more complex when we refer to individuals that are harvested, threatened or are perceived controversially by the public opinion
- ▶ In the above cases, a population may be defined using political and social arguments rather than biological ones
- ▶ For example, Michigan and Wisconsin manage their Wolf (*Canis lupus*) population independently even though they are neighboring states and even though wolf individuals, obviously, move across the boundaries as they please

- ▶ Even if they “feel” artificial, political and social perspectives should always be considered when defining populations, as politicians are the ones that ultimately support or deny conservation policies

- ▶ Populations mutate over time due to individuals **reproducing** or **dying**, **migrating** or **dispersing**
- ▶ Population demography is the study of populations by understanding how probable each one of the above mentioned events is, and what factors influence these probabilities

- ▶ Populations mutate over time due to individuals **reproducing** or **dying**, **migrating** or **dispersing**
- ▶ Population demography is the study of populations by understanding how probable each one of the above mentioned events is, and what factors influence these probabilities
- ▶ Extinction is the event that conservation biologists are trying to avoid
- ▶ Very few populations suddenly disappear when they are large and healthy: extinction is generally preceded by decline!

- ▶ **Cohort:** a group of individuals born at the same time
- ▶ **Survivorship:** the probability of an individual surviving up to a certain age
- ▶ **Recruitment:** the net additions/subtractions of reproductively viable individuals, added to the population after the adjustment for early or neonatal mortality
- ▶ **Fecundity:** the number of young or eggs produced per female (animal) or seeds per individual (plants) per unit time
- ▶ **Dispersal:** the permanent movement of an individual from its area of birth to another area. Usually measured in term of *rate*, *distance* and *direction*

- ▶ If we had perfect knowledge about each individual in the population it would be relatively simple to make precise predictions about the behavior of the population through time
- ▶ Unfortunately, in most cases our knowledge about population status is far from perfect. We therefore construct models to understand and approximate the complexity of a population and predict how it will behave
- ▶ The models and their assumptions are NOT laws that invariably describe how populations work. They have to be informed with direct information gathered from real populations

Population models: exponential

- ▶ The simplest model of population dynamic can be written as the sum of births (**B**) and migrants entering the populations (**I**) minus mortality (**D**) and individuals leaving or exiting the population (**E**)

$$N_{(t+1)} = N_{(t)} + (B_t + I_t) - (D_t + E_t) \quad (4.1)$$

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- ▶ If a population is increasing exponentially (i.e., increasing with and increasing rate over time) its growth will be defined by N and a rate of increase r which is rate of birth minus rate of death ($r = b - d$)
- ▶ Without considering migration (neither in nor out of the population) B becomes a function of birth rate (b), the number of deaths (D) is a function of d the per capita death rate

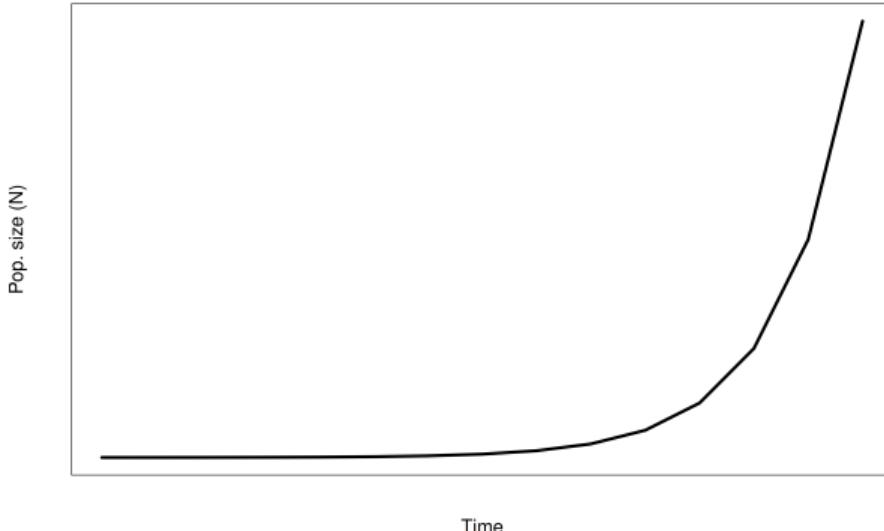


Figure 1: Exponential growth curve

- ▶ Change in numbers over change in time is expressed as:

$$\frac{dN}{dt} = rN \quad (4.2)$$

- ▶ The exponential growth curve is a good starting point, although unrealistic for most species. **Exponential growth has no ecology!** (Boyce, 1992)
- ▶ A more realistic model should account for species' ecology and the fact that species exist in their environment
- ▶ The limits imposed by the environment are usually identified using K , i.e. the carrying capacity

$$\frac{dN}{dt} = rN\left(\frac{K - N}{K}\right) \quad (4.3)$$

- ▶ With small values of N relative to K , $(\frac{K-N}{K}) \approx 1$ and the population grows almost exponentially

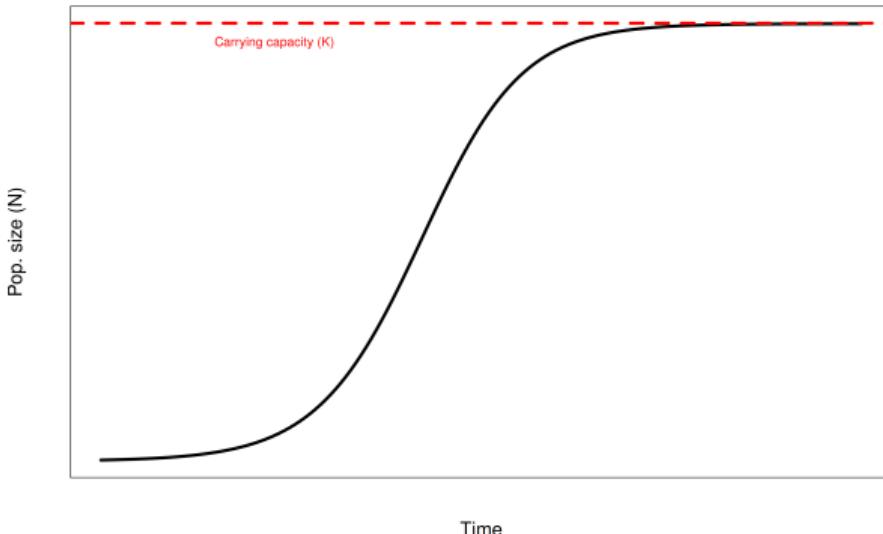


Figure 2: Logistic growth curve

- ▶ This model assumes all individuals are demographic equivalent, an unlikely assumption in many systems, especially with long lived individuals!

- ▶ In logistic model, changes in the size of the population (N) directly affect population growth, an expression of **density dependence**
- ▶ Density dependence operates through a negative feedback between the growth rate and the population size at one or more steps
- ▶ Density dependence results in regulation of the population fluctuations around a mean population size, which is the carrying capacity

- ▶ Many factors influencing population size are described as stochastic factors
- ▶ A population whose growth is only a function of stochastic variation can be described as density independent. Shaffer (1981) recognizes 4 main sources of such stochasticity:
 - ▶ genetic stochasticity;
 - ▶ demographic stochasticity;
 - ▶ environmental stochasticity
 - ▶ natural catastrophes!
- ▶ The effects of these sources of variation are not predetermined, but subject to uncertainties that are more or less probable according to population characteristics

Population perturbations: natural catastrophes!

- ▶ Some have argued that natural catastrophes are a special case of environmental stochasticity because they are only extreme forms of normal environment variation (prolonged drought, flash floods, extreme rain)
- ▶ The point is that catastrophes lie outside of the normal probability distribution of random events associated with environmental variation
- ▶ They also are qualitatively and quantitatively different in their effects
- ▶ A forest fire is not just a very hot day! (Lacy, 1993)
- ▶ The most viable protection against risks associated with catastrophes is spatial segregation of different population subunits (Dyke & Lamb, 2020)

Avoiding extinction through spatial segregation

- What are the relative risks of keeping a small population intact on a single site versus subdividing the population in to separate units?

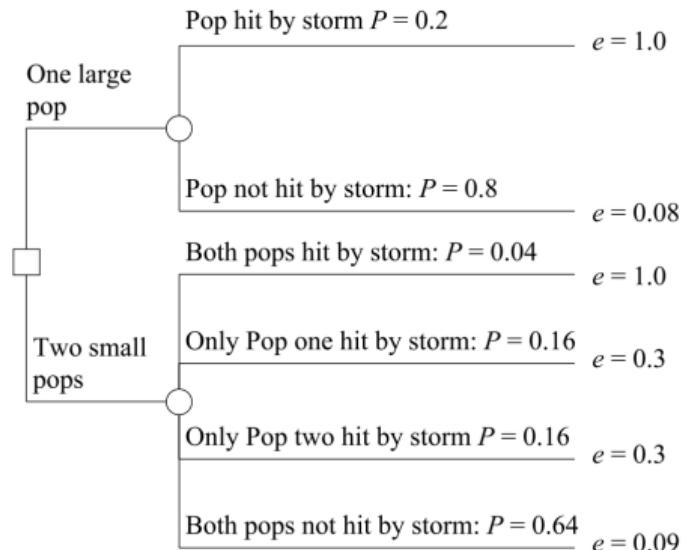


Figure 3: Decision analysis after Drechsler & Burgman (2004)

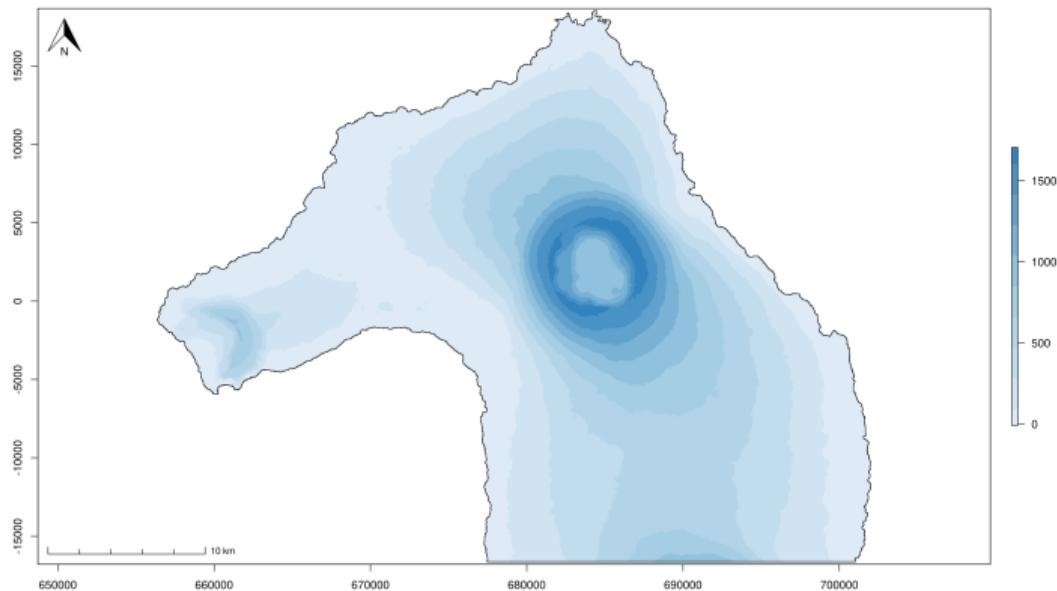


Figure 4: The pink iguana population only persists on the top of an active volcano!

- ▶ Density dependent factors can regulate the size of a population in a much more precise way than the independent ones
- ▶ To better understand these factors it is useful to debunk the assumptions of the logistic growth curves
 - ▶ Time lag in density dependence: the addition of new individuals in the population may not have an immediate effect in shaping the growth curve
 - ▶ Traditional logistic curves assume constant values of K: it is more accurate to define K not as a constant value that a population cannot exceed, but as a population size reflecting equilibrium between a population and its resources created by their interaction
 - ▶ Individuals in a population are not contributing equally to the population growth: age and sex structure play a pivotal role

How do we estimate the size of a population?

- ▶ It is often impractical and/or impossible to count every single individual in a population

How do we estimate the size of a population?

- ▶ It is often impractical and/or impossible to count every single individual in a population
- ▶ Capture-Mark-Recapture experiments allow to estimate a population's size
 - ▶ Some individuals are captured and marked
 - ▶ The marked individuals are released in their environment
 - ▶ A second sampling trip is conducted and another portion of the individuals are collected
 - ▶ The number of marked individuals collected in the second expedition is expected to be proportional to the number of marked individuals in the entire population

- ▶ A tagging system is a system allowing us to tag and label things to provide those things a unique identifier
- ▶ People have been tagging animals (wild and captive) for hundreds of years and have developed different ways to tag pretty much every single living things
- ▶ An animal tag can be as simple as a piece of metal or plastic with a number carved on it or with a standardized meaning

Visual tagging systems



Figure 5: A male *Cyclura carinata* with colored bead tags. Photo credits: Giuliano Colosimo.

Passive integrated transponders

- ▶ Tags based on radio-frequency identification (RFID)
- ▶ Emit a signal with an alpha-numeric code unique to the animal
- ▶ Widely used for wildlife fauna
- ▶ They generally do not carry any other information but the ID



Figure 6: A Passive Integrated Transponder by Trovan®. Photo credits: Giuliano Colosimo.

Patterns tagging

Toes and nail clipping

Table 1. All codes possible by clipping one, two, or three toes. The codes available only for animals with five fore toes are printed in bold.

ONE	A4B2	B5C5	A1A3D4	A3A4C2	B1B4D5	B3B5C3	C2C3A1	C4C5B4	D2D4A2	A1B1D5	A2B5C3
TOE	A4B3	B5D1	A1A3D5	A3A4C3	B1B5A1	B3B5C4	C2C3A2	C4C5B5	D2D4A3	A1B2C1	A2B5C4
	A4B4	B5D2	A1A4B1	A3A4C4	B1B5A2	B3B5C5	C2C3A3	C4C5D1	D2D4A4	A1B2C2	A2B5C5
A1	A4B5	B5D3	A1A4B2	A3A4C5	B1B5A3	B3B5D1	C2C3A4	C4C5D2	D2D4A5	A1B2C3	A2B5D1
A2	A4C1	B5D4	A1A4B3	A3A4D1	B1B5A4	B3B5D2	C2C3A5	C4C5D3	D2D4B1	A1B2C4	A2B5D2
A3	A4C2	B5D5	A1A4B4	A3A4D2	B1B5A5	B3B5D3	C2C3B1	C4C5D4	D2D4B2	A1B2C5	A2B5D3
A4	A4C3	C1C2	A1A4B5	A3A4D3	B1B5C1	B3B5D4	C2C3B2	C4C5D5	D2D4B3	A1B2D1	A2B5D4
A5	A4C4	C1C3	A1A4C1	A3A4D4	B1B5C2	B3B5D5	C2C3B3	D1D2A1	D2D4B4	A1B2D2	A2B5D5
B1	A4C5	C1C4	A1A4C2	A3A4D5	B1B5C3	B4B5A1	C2C3B4	D1D2A2	D2D4B5	A1B2D3	A3B1C1
B2	A4D1	C1C5	A1A4C3	A3A5B1	B1B5C4	B4B5A2	C2C3B5	D1D2A3	D2D4C1	A1B2D4	A3B1C2
B3	A4D2	C1D1	A1A4C4	A3A5B2	B1B5C5	B4B5A3	C2C3D1	D1D2A4	D2D4C2	A1B2D5	A3B1C3
B4	A4D3	C1D2	A1A4C5	A3A5B3	B1B5D1	B4B5A4	C2C3D2	D1D2A5	D2D4C3	A1B3C1	A3B1C4
B5	A4D4	C1D3	A1A4D1	A3A5B4	B1B5D2	B4B5A5	C2C3D3	D1D2B1	D2D4C4	A1B3C2	A3B1C5
C1	A4D5	C1D4	A1A4D2	A3A5B5	B1B5D3	B4B5C1	C2C3D4	D1D2B2	D2D4C5	A1B3C3	A3B1D1
C2	A5B1	C1D5	A1A4D3	A3A5C1	B1B5D4	B4B5C2	C2C3D5	D1D2B3	D2D5A1	A1B3C4	A3B1D2
C3	A5B2	C2C3	A1A4D4	A3A5C2	B1B5D5	B4B5C3	C2C4A1	D1D2B4	D2D5A2	A1B3C5	A3B1D3
C4	A5B3	C2C4	A1A4D5	A3A5C3	B2B3A1	B4B5C4	C2C4A2	D1D2B5	D2D5A3	A1B3D1	A3B1D4
C5	A5B4	C2C5	A1A5B1	A3A5C4	B2B3A2	B4B5C5	C2C4A3	D1D2C1	D2D5A4	A1B3D2	A3B1D5
D1	A5B5	C2D1	A1A5B2	A3A5C5	B2B3A3	B4B5D1	C2C4A4	D1D2C2	D2D5A5	A1B3D3	A3B2C1
D2	A5C1	C2D2	A1A5B3	A3A5D1	B2B3A4	B4B5D2	C2C4A5	D1D2C3	D2D5B1	A1B3D4	A3B2C2
...

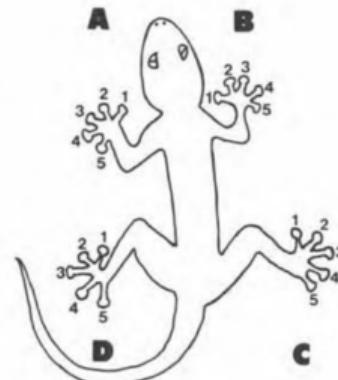


Fig. 1. Labeling system for feet and toes.

A4B3D1 A5B5C1 C2D1B1 C3D3A1 C4D4B3
 A4B3D2 A5B5C2 C2D1B2 C3D3A2 C4D4B4

Figure 7: This image is from Waichman (1992). The author describes all possible combination of toe clipping to uniquely identify individuals

Features tag



Figure 8: Toads of the genus *Bombina* have unique spotted patterns. Photo credits: [marioeffe](#)

Photo tagging

Results : individual identification of Lesser Antillean Iguanas

- ▶ Matching individual pictures in I3S

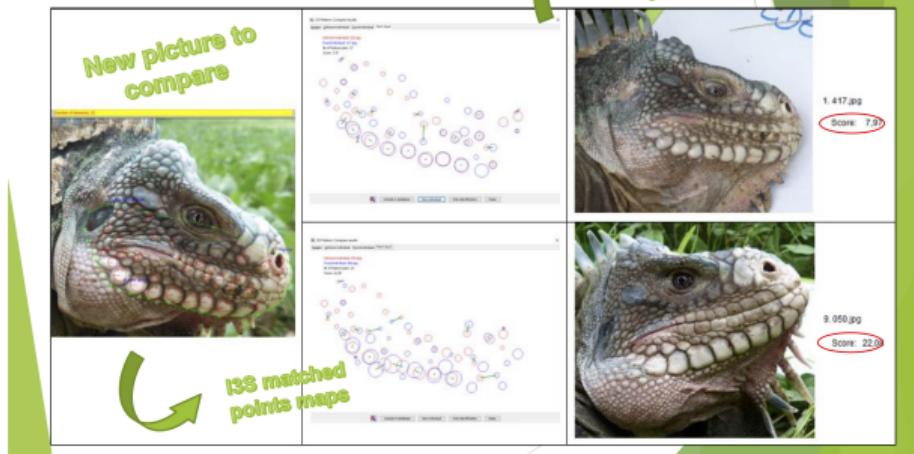


Figure 9: Development of a photo recognition software to identify iguanas in the wild. Image courtesy of Nathalie Duporge.

Satellite tags



Figure 10: A male *Conolophus marthae* with a Wireless Sensor Node (WSN) attached behind its hindlegs. Photo credits: Giuliano Colosimo.

- ▶ A conservationist is working on a critical endangered species and needs to estimate how many individuals are left. He/she goes to the field and captures 15 individuals. These individuals are tagged and released on site. One week later the researcher comes back and catches 20 individuals, 10 of which are tagged
- ▶ Lets define some variables as:
 - ▶ N = Number of animals in the population
 - ▶ n = Number of animals marked on the first visit
 - ▶ K = Number of animals captured on the second visit
 - ▶ k = Number of animals captured in the second visit that were marked (i.e., recaptured individuals)

- ▶ Useful with only two sampling events
- ▶ Assumes that N is constant over the time of the experiment (i.e., there are no deaths or births)
- ▶ Assumes a closed population (i.e., there are no migrants)
- ▶ Catchability is the same among individuals, even the tagged ones
- ▶ Tags are not lost between sampling events
- ▶ Individuals have the time to randomly redistribute over their habitat

- ▶ N = Number of animals in the population
- ▶ n = Number of animals marked on the first visit
- ▶ K = Number of animals captured on the second visit
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$$N = \frac{K * n}{k} \quad (4.4)$$

- ▶ Extension of the LP estimator
- ▶ Same assumptions of LP
- ▶ Allows to incorporate s sampling events in the calculation
- ▶ It depends simply on observing how the proportion of marked animals in catches increases as more animals have been marked (Sutherland, 2006)

- ▶ N = Number of animals in the population
- ▶ n_i = Number of animals captured on i^{th} visit
- ▶ m_i = Number of animals marked on i^{th} visit
- ▶ k_i = Number of animals captured on i^{th} visit that were marked
(i.e., recaptured individuals)
- ▶ s = Number of visits

$$N = \frac{\sum_{i=1}^s n_i * m_i}{\sum_{i=1}^s k_i} \quad (4.5)$$

- ▶ Jolly-Seber (Jolly, 1965; Seber, 1982) is the method of election to estimate N starting from multiple sampling occasions
- ▶ The following set of four numbers are needed in order to begin the calculation
 - ▶ n_i = total number of animals caught in the i^{th} sample
 - ▶ R_i = number of animals that are released after the i^{th} sample
 - ▶ m_i = number of animals in the i^{th} sample that carry marks from previous captures
 - ▶ m_{ij} = number of animals in the i^{th} sample that were most recently caught in the j^{th} sample

Animal	Occasion			Animal	Occasion		
	1	2	3		1	2	3
1	1	1	1	20	1	1	1
2	1	1	0	21	0	1	0
3	1	0	1	22	0	1	1
4	1	0	0	23	0	1	1
5	1	1	0	24	0	1	0
6	1	1	1	25	0	1	1
7	1	0	1	26	0	1	0
8	1	1	1	27	0	1	1
9	1	1*	0	28	0	1	0
10	1	0	1	29	0	1*	0
11	1	1	0	30	0	1	0
12	1	0	1	31	0	1	1
13	1	1	1	32	0	0	1
14	1*	0	0	33	0	0	1
15	1	0	0	34	0	0	1
16	1	1	1	35	0	0	1
17	1	0	1	36	0	0	1
18	1	0	0	37	0	0	1
19	1	0	0	38	0	0	1
n_i				20	21	23	
Not released					1	2	
R_i					19	19	

Figure 11: Capture history of sampled individuals. After Sutherland (2006), p. 121

Occasion			No.	m_2	m_3	m_{21}	m_{31}	m_{32}
1	2	3	6	6	6	6		6
1	1	0	4	4		4		
1	0	1	5		5		5	
1	0	0	5					
0	1	1	5		5			5
0	1	0	6					
0	0	1	7					
			Sums	10	16	10	5	11

Figure 12: Summary of capture data from previous table. After Sutherland (2006), p. 121

- ▶ z_i = the number of animals caught both before and after the i^{th} sample but not in the i^{th} sample itself
- ▶ r_i = the number of animals that were released from the i^{th} sample and were subsequently recaptured (Sutherland, 2006)
- ▶ M_i = number of marked animals in the population when the i^{th} sample is taken (but not including animals newly marked in the i^{th} sample)

$$m_1 + (R_i + 1)z_i / (r_i + 1) \quad (4.6)$$

	<i>i</i>												
	1	2	3	4	5	6	7	8	9	10	11	12	13
n_i	54	146	169	209	220	209	250	176	172	127	123	120	142
R_i	54	143	164	202	214	207	243	175	169	126	120	120	0
<i>i</i>													
1		10	3	5		2	2	1	0	0	0	1	0
2			34	18		8	4	6	4	2	0	2	1
3				33		13	8	5	0	4	1	3	3
4					30	20	10	3	2	2	1	1	2
5						43	34	14	11	3	0	1	3
6							56	19	12	5	4	2	3
7								46	28	17	8	7	2
8									51	22	12	4	10
9										34	16	11	9
10											30	16	12
11												26	18
12													35
m_i	0	10	37	56	53	77	112	86	110	84	77	72	95
z_i	0	14	57	71	89	121	110	132	121	107	88	60	
r_i	24	80	70	71	109	101	108	99	70	58	44	35	

Figure 13: Capture history data sourced from Jolly (1965)

- ▶ N_i = population size at the time of the i^{th} sample

$$M_i(n_i + 1)/(m_i + 1) \quad (4.7)$$

- ▶ ϕ_i = proportion of the population surviving (and remaining in the study area) from the i^{th} sampling occasion to the $(i + 1)^{th}$

$$M_{i+1}/(M_i - m_i + R_1) \quad (4.8)$$

- ▶ B_i = number of animals that enter the population between the i^{th} and $(i + 1)^{th}$ samples and survive until the $(i + 1)^{th}$ sampling occasion

$$N_{i+1} - \phi_i(N_i - n_i + R_i) \quad (4.9)$$

- ▶ $M_2 = 10 + (143 + 1)14/(80 + 1) = 34.89$
- ▶ $N_2 = 34.89(146 + 1)/(10 + 1) = 466.1$
- ▶ $\phi_2 = 169.46/(34.89 - 10 + 143) = 1.009$
- ▶ $B_2 = 758.1 - 1.009(466.2 - 146 + 143) = 290.7$
- ▶ Note that one cannot calculate M for the last sample, N for the first or last, ϕ for the last two and B for the first or last two. M_1 is always zero

Distance sampling

- ▶ This method is based on performing transects during which the user collects the distances of the surveyed individuals from a line or point
- ▶ The goal is to estimate the density of individuals within a region

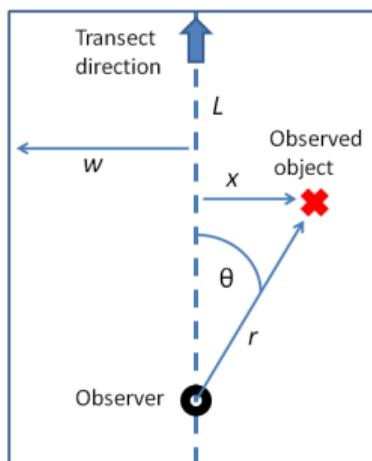


Figure 14: Distance sampling using line transect. Downloaded [here](#)

- ▶ Distance sampling assumes perfect detectability on the walking transect line

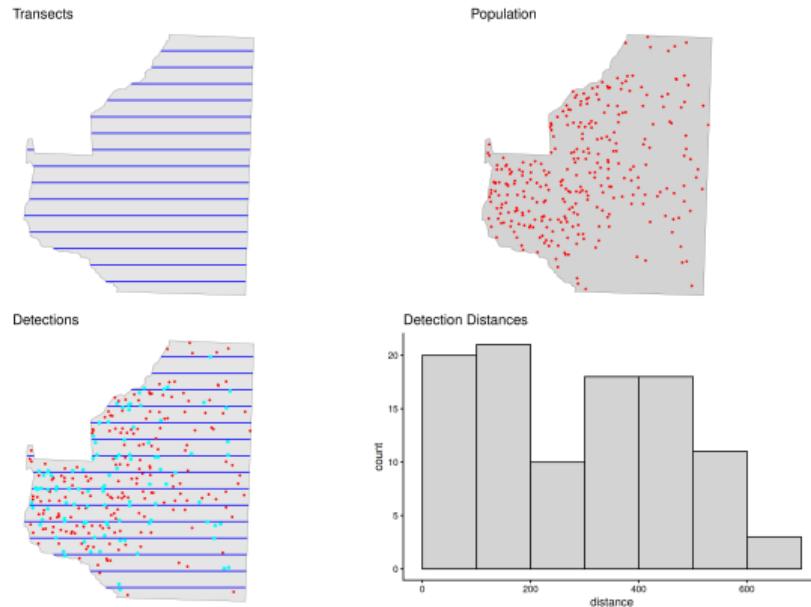


Figure 15: Example survey from systematic parallel design. Data downloaded [here](#)

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