Monitoring biodiversity from space: a wealth of opportunities

Nathalie Pettorelli

ZSL Institute of Zoology
LIVING CONSERVATION

A century of global changes

And species that try to adapt

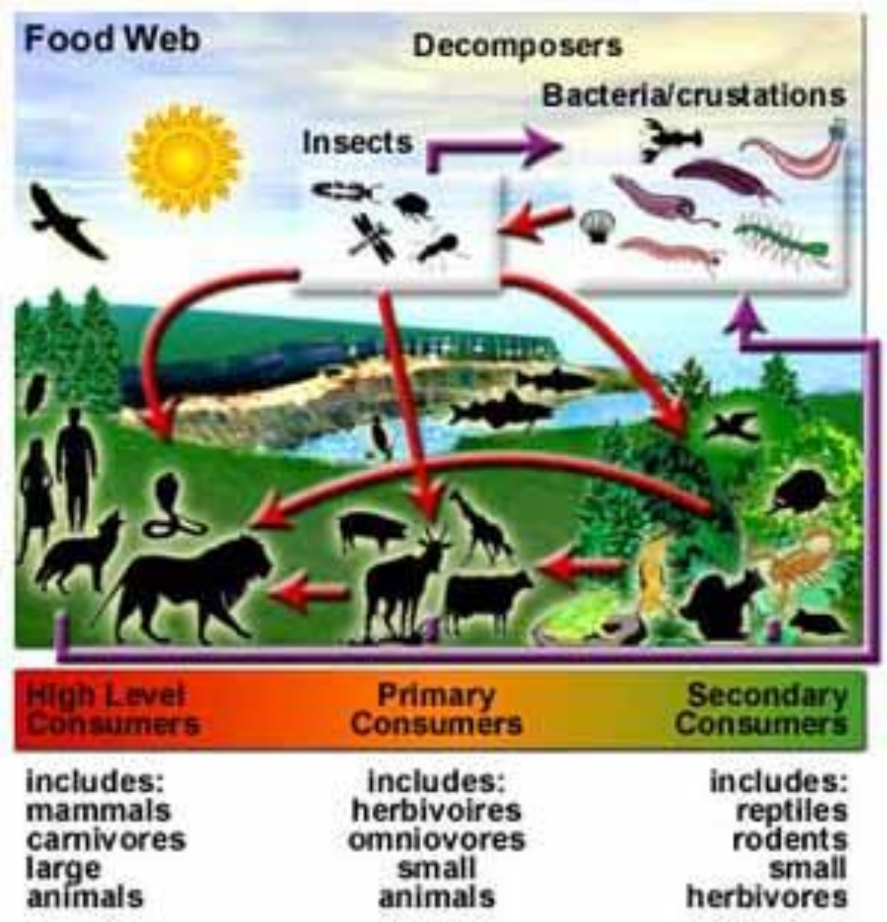
- Diet change
- Variation in species' life history traits, in their dynamics
- Modification in temporal patterns (earlier start of the vegetation, shorter hibernation time, advanced arrival for some migrating species, earlier egg laying time)
- Modification in spatial patterns (reduction/increase of the species' distribution zones)

➔ Biodiversity loss

Importance of the trophic interactions

- Priority: To determine how environmental changes affect habitats and animal populations

- To predict ecological responses to environmental changes is a function of understanding and quantifying trophic interactions



Monitoring habitats

ZSL

Field data:

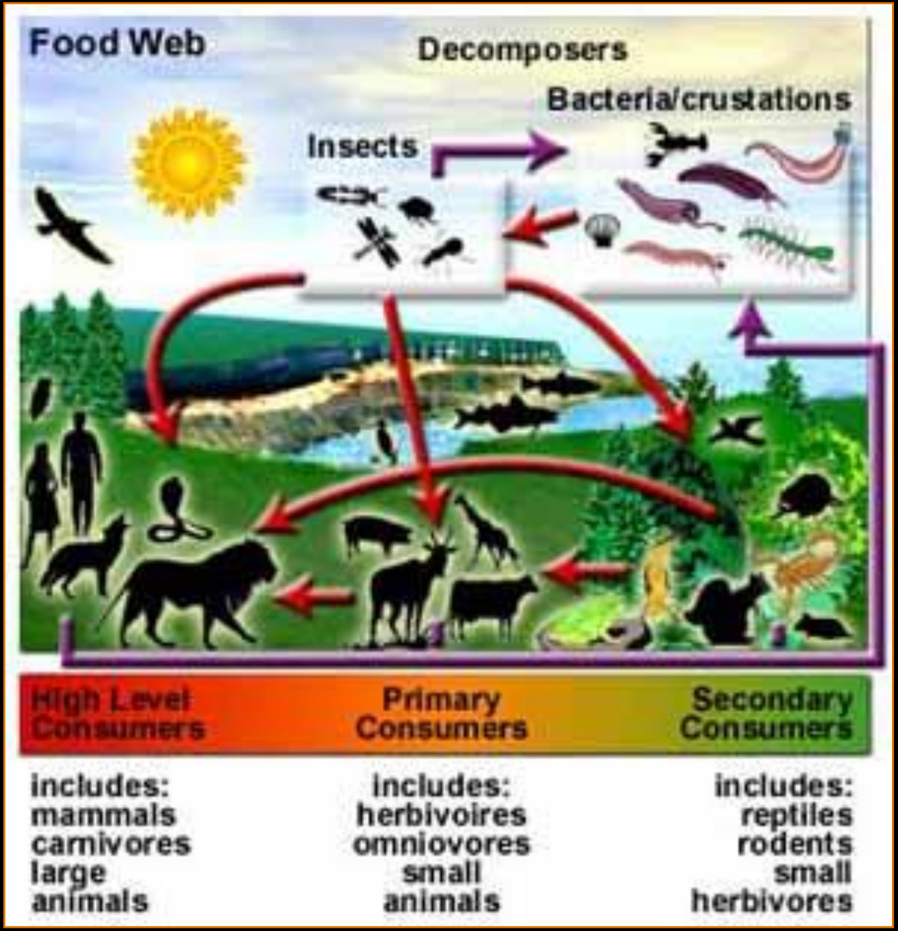
- Little restriction on what can be monitored

BUT:

- Traditionally collected at small spatial and temporal scales
- Vary in their type and reliability
- Generally difficult to use for assessing or predicting regional or global habitat changes

Importance of the trophic interactions

- Priority: Determine how environmental changes affect habitats and animal populations
- Predict ecological responses to environmental change = understanding and quantifying trophic interactions
- Little information on habitat composition and dynamics at large temporal and spatial scales

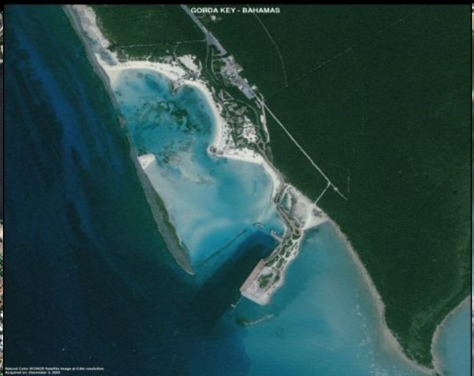


Importance of remote sensing data!

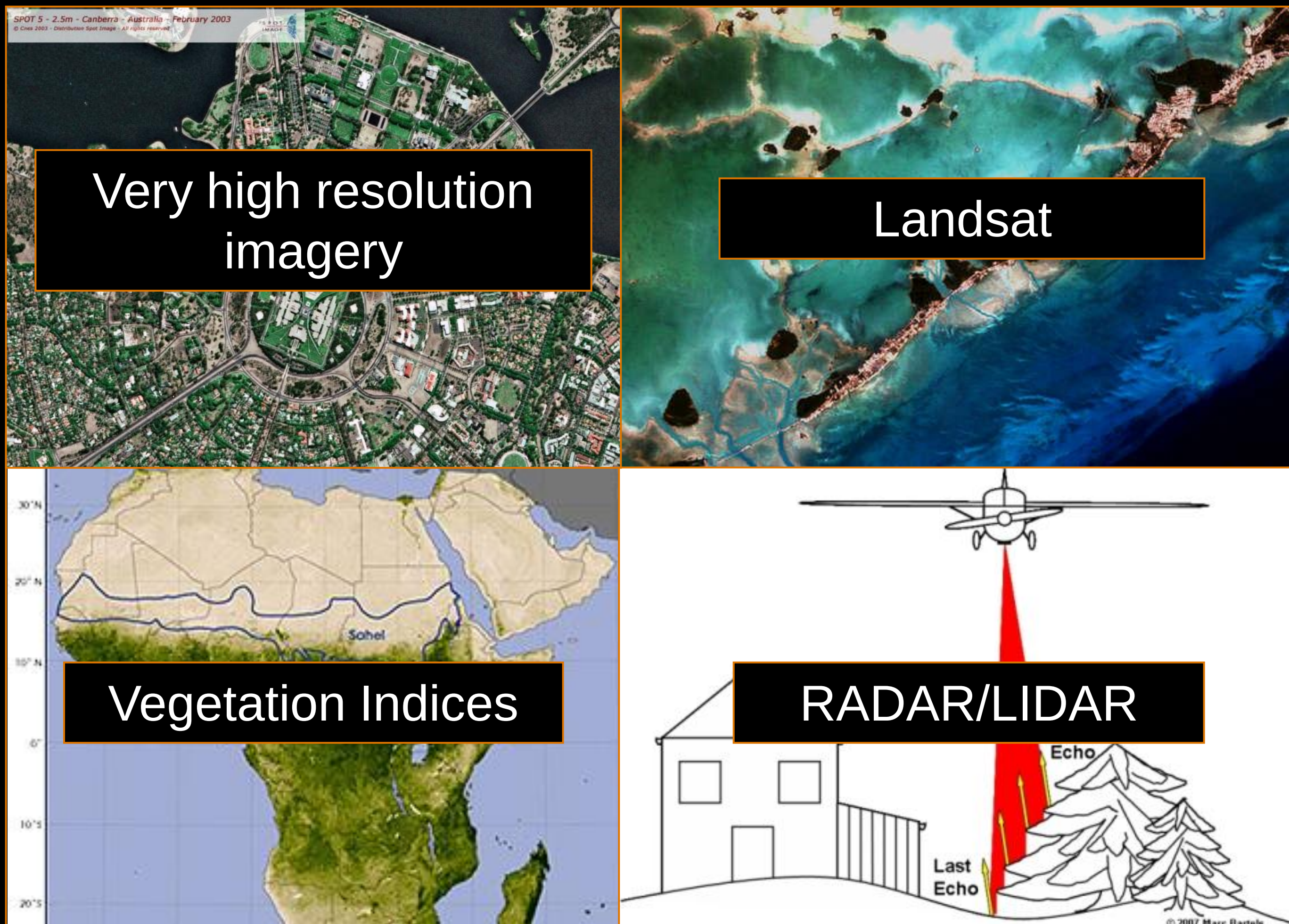
How can remote sensing help ecologists?

Strength of Remote sensing methods :

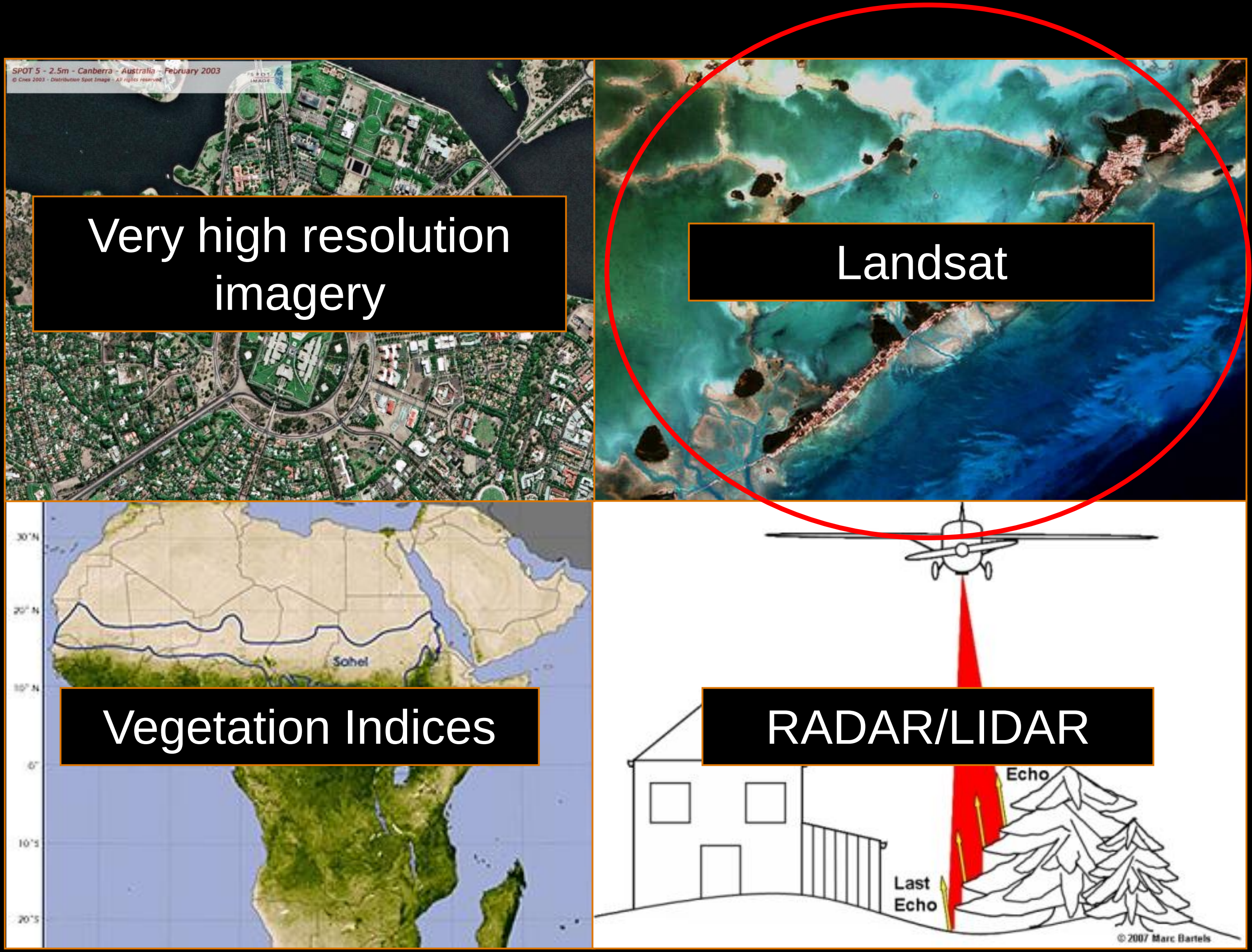
(1) Relatively cheap / less costly than field monitoring at such scale
(2) World coverage
(3) Reproducible, sustainable methodologies
(4) Standardized & transparent information
(5) Information can be down-scaled to allow verification using ground-based methodologies



How can remote sensing help ecologists?

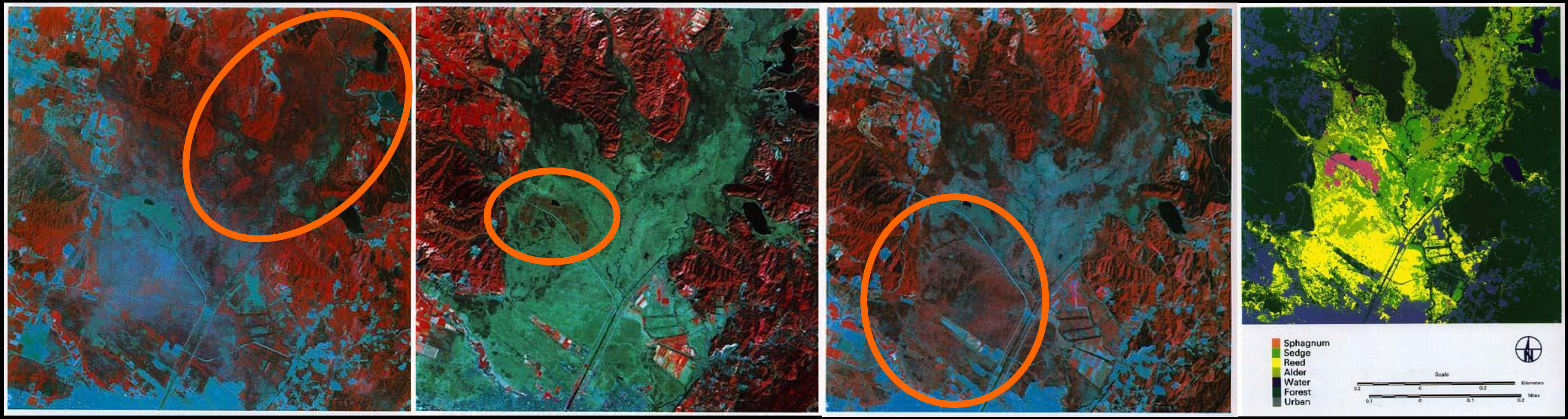


How can remote sensing help ecologists?



Landsat & habitat monitoring

- Landsat started in the late seventies; 30m spatial resolution (Landsat 7)
- Landsat satellites use an instrument that collects several images at once. Each image shows a specific section of the electromagnetic spectrum, called a band
- The combination of the information encapsulated in the different bands allows differentiating habitats
- Ground truth generally needed, in order to relate image data to real features and materials on the ground (calibration)

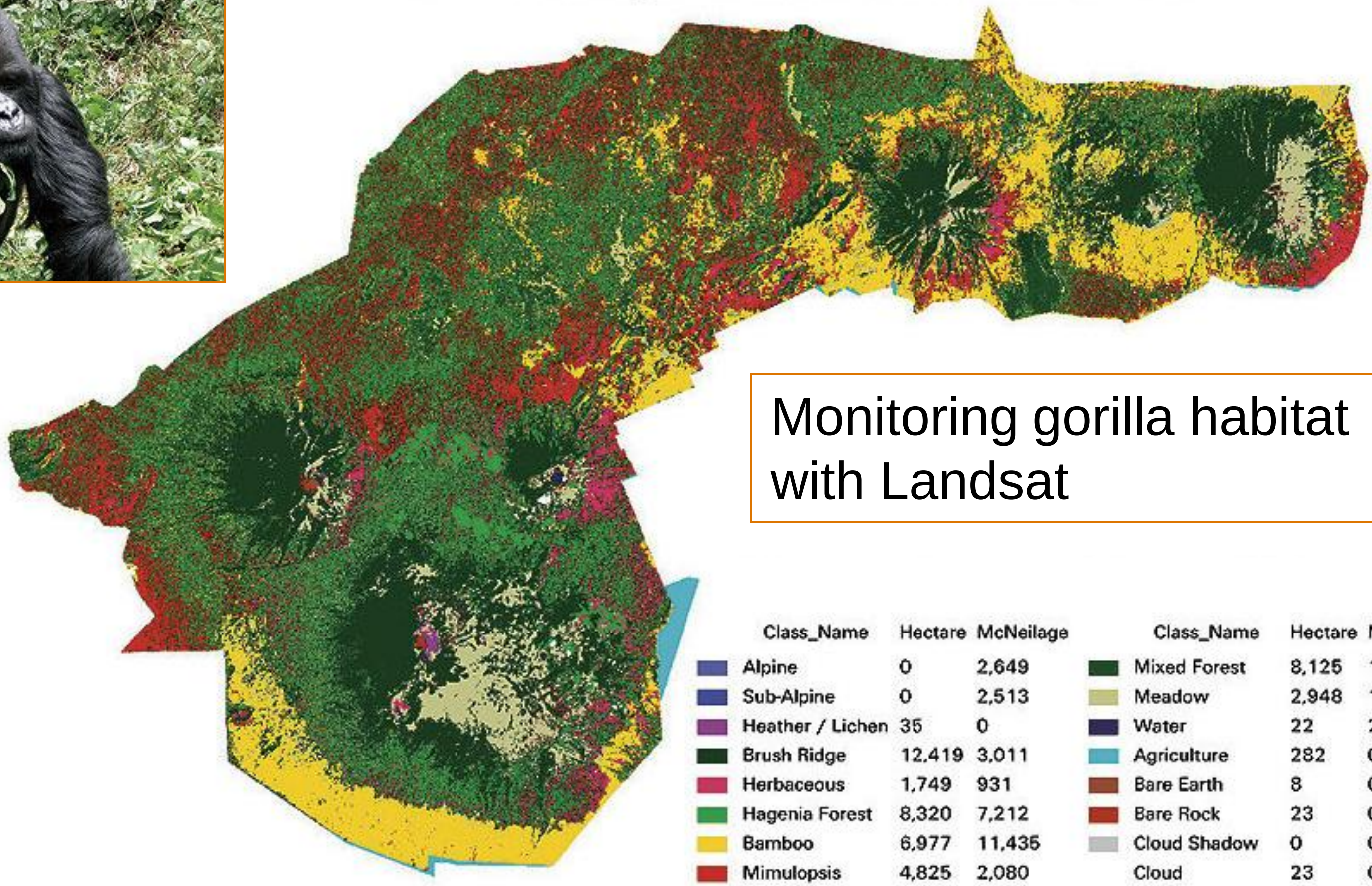


Landsat & habitat monitoring

Band Number	Wavelength Interval	Spectral Response	
1	0.45-0.52 µm	Blue-Green	**Bathymetric map, forest type**
2	0.52-0.60 µm	Green	**High reflectance vegetation**
3	0.63-0.69 µm	Red	**High absorbance vegetation**
4	0.76-0.90 µm	Near IR	**High reflectance vegetation**
5	1.55-1.75 µm	Mid-IR	**Soil moisture, rock/mineral**
6	10.40-12.50 µm	Thermal IR	**Thermal map, soil moisture**
7	2.08-2.35 µm	Mid-IR	**Soil moisture, rock/mineral**

Landsat & habitat monitoring

2003 Virunga Landsat TM Classification



Monitoring gorilla habitat with Landsat

Class_Name	Hectare	McNeilage	Class_Name	Hectare	McNeilage
Alpine	0	2,649	Mixed Forest	8,125	13,832
Sub-Alpine	0	2,513	Meadow	2,948	1,205
Heather / Lichen	35	0	Water	22	21
Brush Ridge	12,419	3,011	Agriculture	282	0
Herbaceous	1,749	931	Bare Earth	8	0
Hagenia Forest	8,320	7,212	Bare Rock	23	0
Bamboo	6,977	11,435	Cloud Shadow	0	0
Mimulopsis	4,825	2,080	Cloud	23	0

A Landsat 7 Jan. 31, 2003 pan - multispectral merged image was used for > 97.5% of Classified area. A Landsat 5 Aug. 8, 1987 image was used for most of the clouded areas fom the 2003 image (<2.5%).

Total Area: Current Class 45,755 Ha
McNeilage 44,891 Ha

Steklis et al. 2005

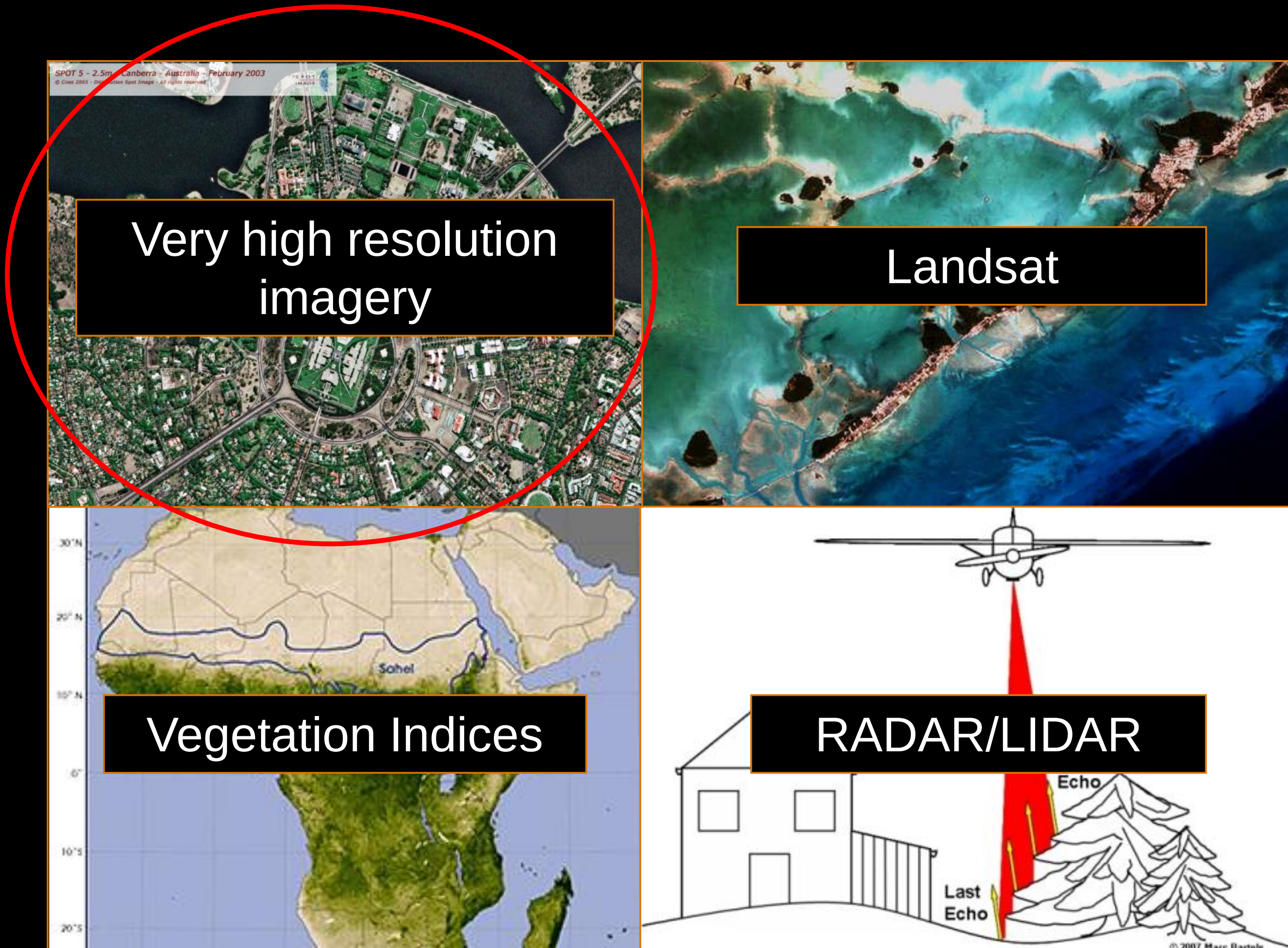
Landsat & habitat monitoring

Monitoring coral reef with Landsat

NASA program based on Landsat 7 data – assessment of the extent & condition

http://visibleearth.nasa.gov/

How can remote sensing help ecologists?



Monitoring at very high resolution

- SPOT: First satellite launched in 1986; range of resolutions from 20 m down to 2.5 m (since 2002)
- IKONOS: images available from 2000, 1 to 4 m resolution
- QUICKBIRD: launched in 2001, 60 cm to 2.8 m resolution
- GEOEYE: launched in 2008, 41 cm to 1.65 m resolution, *currently the world's highest resolution commercial earth-imaging satellite*

Monitoring penguins from space

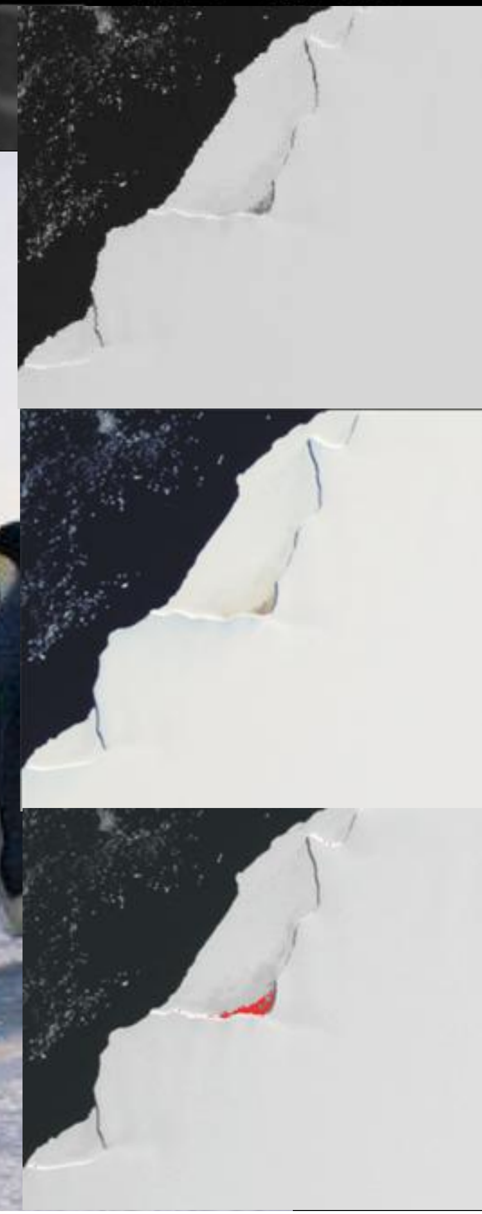


Figure 1 Comparison of data types: (a) screenshot of online Landsat Image Mosaic of Antarctica (LIMA); (b) Landsat ETM tile, downloaded from the LIMA website – note brown staining at the colony location; (c) spectral analysis red minus blue band, positive values shown in red, picking out the exact area of the colony.

Fretwell & Trathan 2009

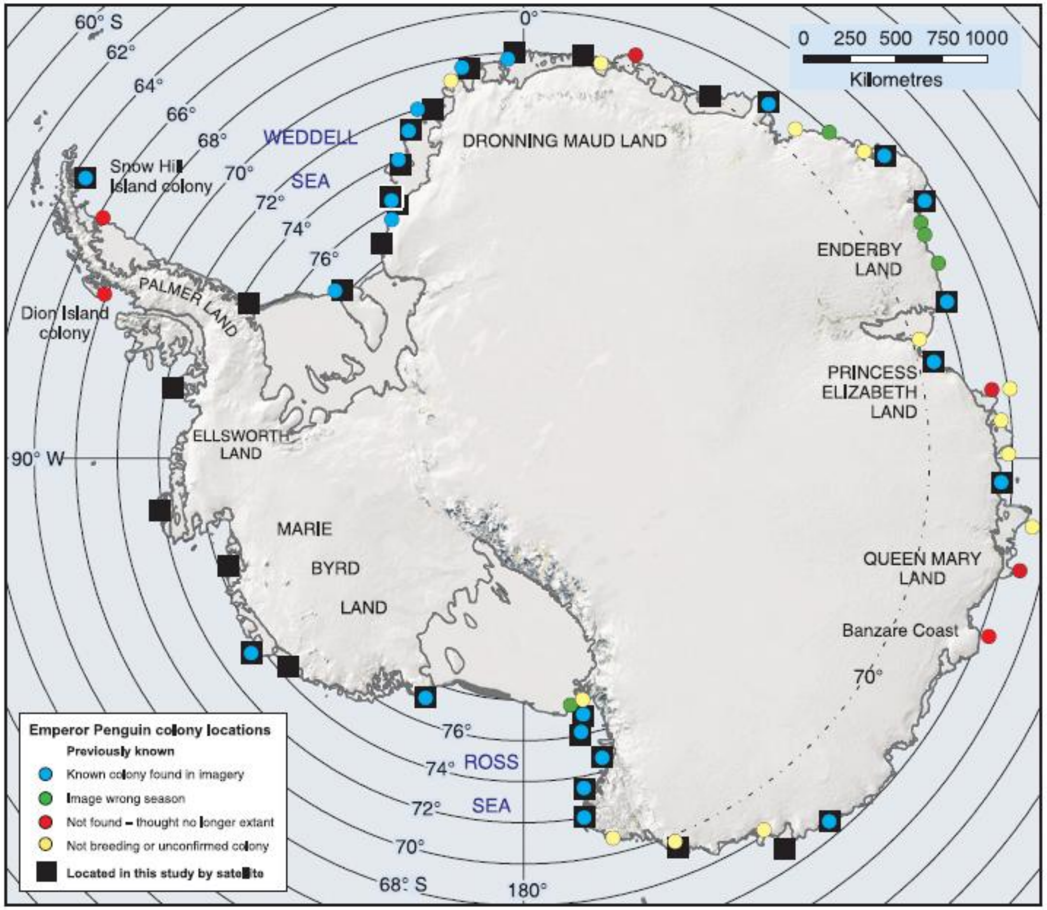


Figure 3 Distribution of emperor penguins found in this study versus previously recorded breeding sites. Black squares show locations found in this study. Other coloured dots relate to previously known sites: blue are those that have been located by satellite in the correct position, green dots are those that have not been identified due to the imagery being too late in the season; yellow dots are records of sightings but no breeding colony; red dots are those colonies that have not been found and are believed to no longer be extant.

Fretwell & Trathan 2009

From Landsat to Very High Resolution Imagery

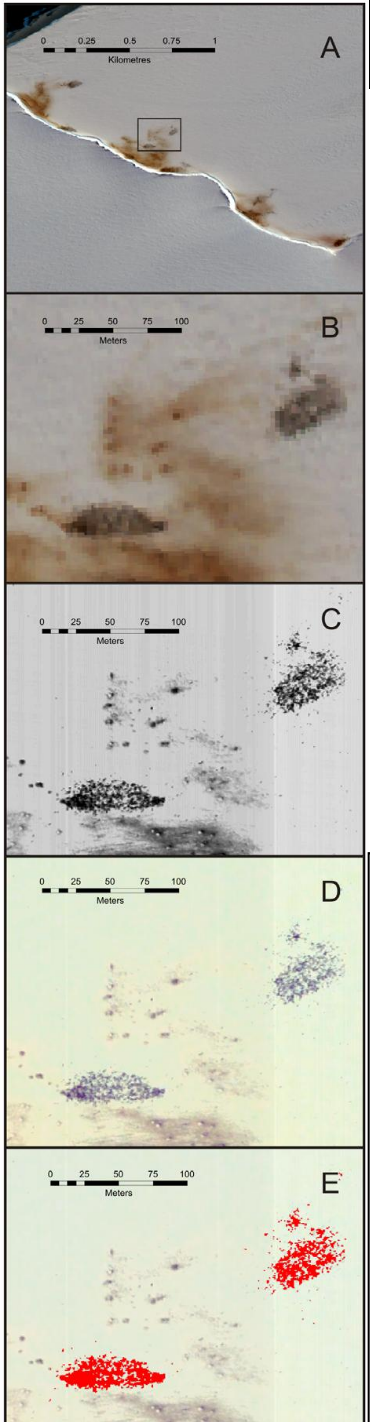
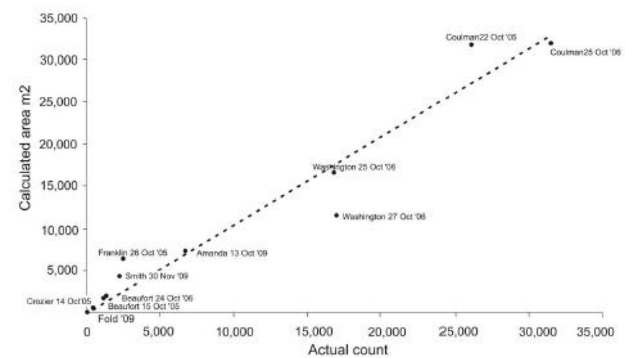
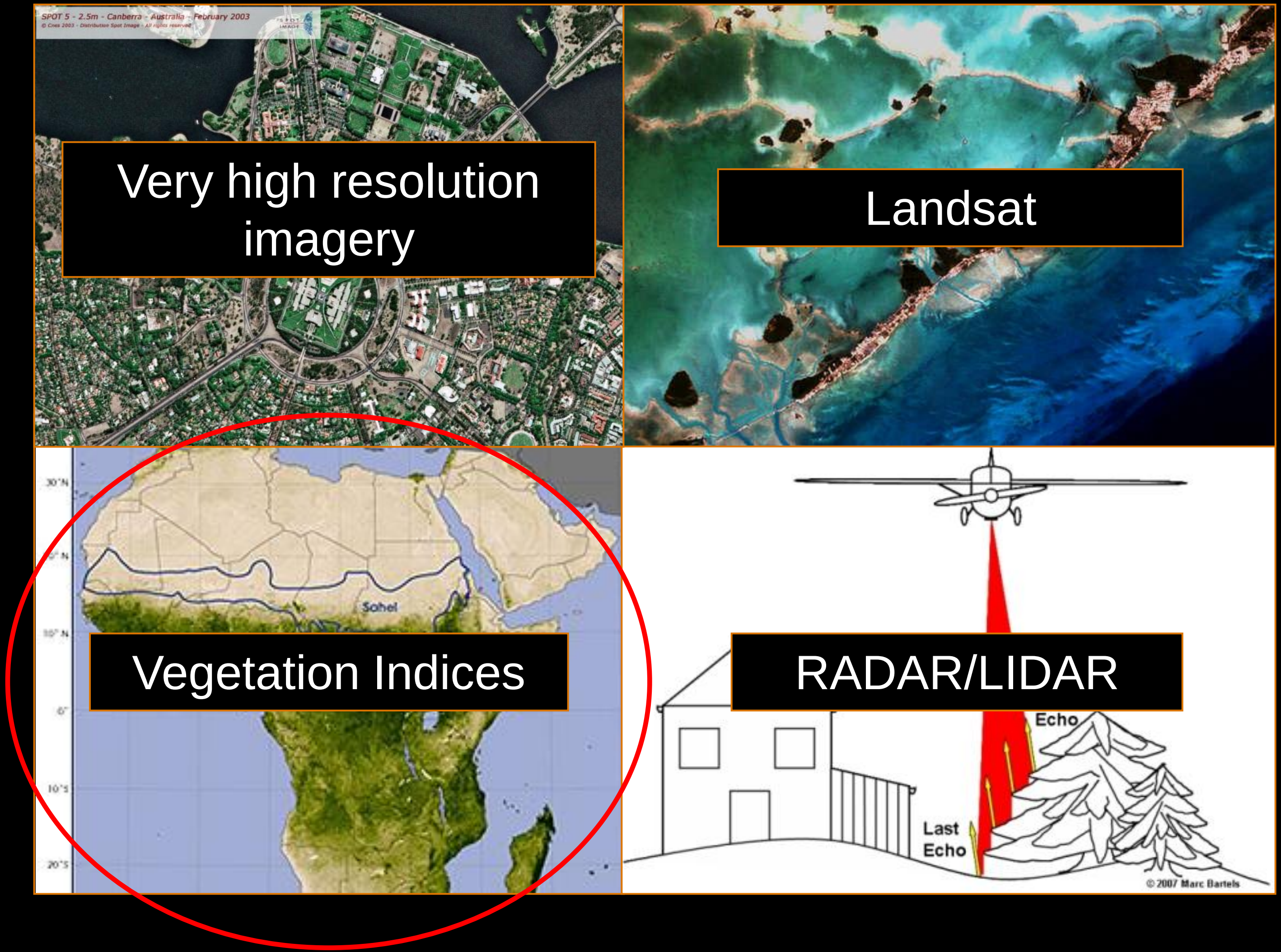


Figure 1. Example of imagery used in analysis. A: Multispectral QuickBird image of the emperor penguin colony at Windy Creek, Halley Bay, Antarctica. Black box indicates the area of images B–E below. B: Detail of multispectral image showing area of penguins as black/grey pixels and guano in brown. Although there is good differentiation between penguins and guano the coarse resolution of the multispectral image (2.54 m cell size) means that individual penguins cannot be identified and limits the usefulness of the image. C: Detail of the panchromatic band of the corresponding QuickBird image. The higher resolution (61 cm) gives better detail of the penguin area, but many of the penguin pixels have the same value as the areas of guano and therefore are difficult to separate using a classification index. D: Detail of the corresponding pansharpened QuickBird image. A histogram stretch has been used to maximize the difference between penguins and guano. Using this method the image retains the detail of the panchromatic image while keeping the colour differentiation of the multispectral image. E: Results from the supervised classification analysis of the pansharpened QuickBird image with the area classified as penguins shown in red.
doi:10.1371/journal.pone.0033751.g001



Fretwell et al. 2012

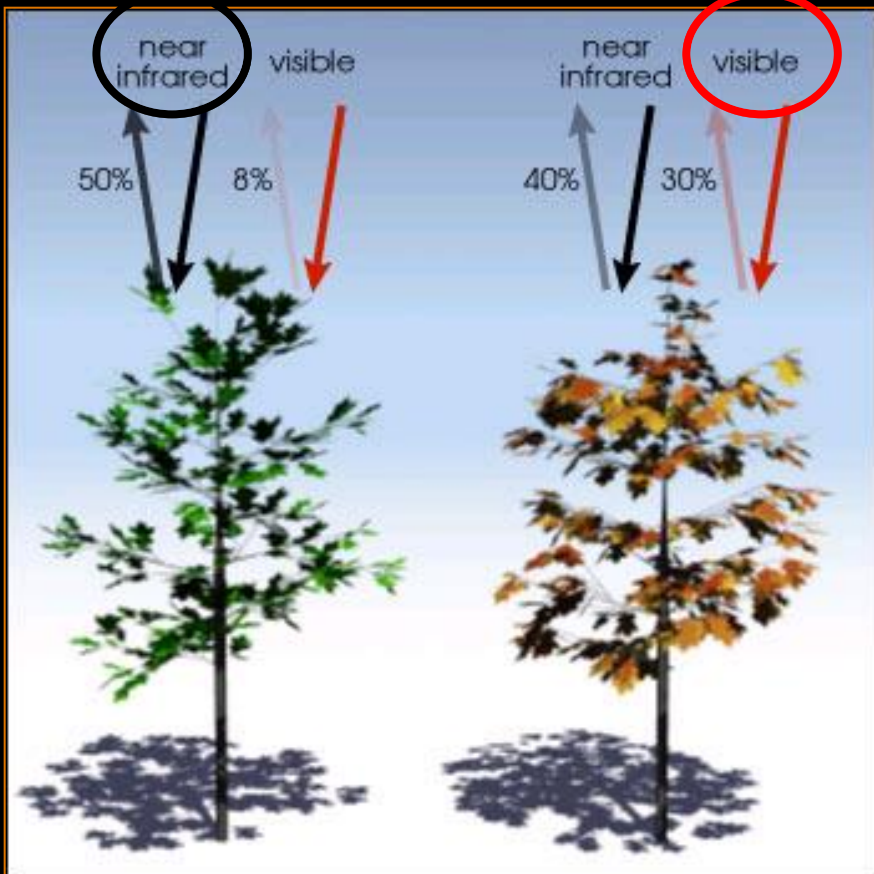
How can remote sensing help ecologists?



Vegetation Indices & NDVI

reflects

absorbs



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

➔ The Normalized Difference Vegetation Index:

NDVI=(NIR-RED)/(NIR+RED)

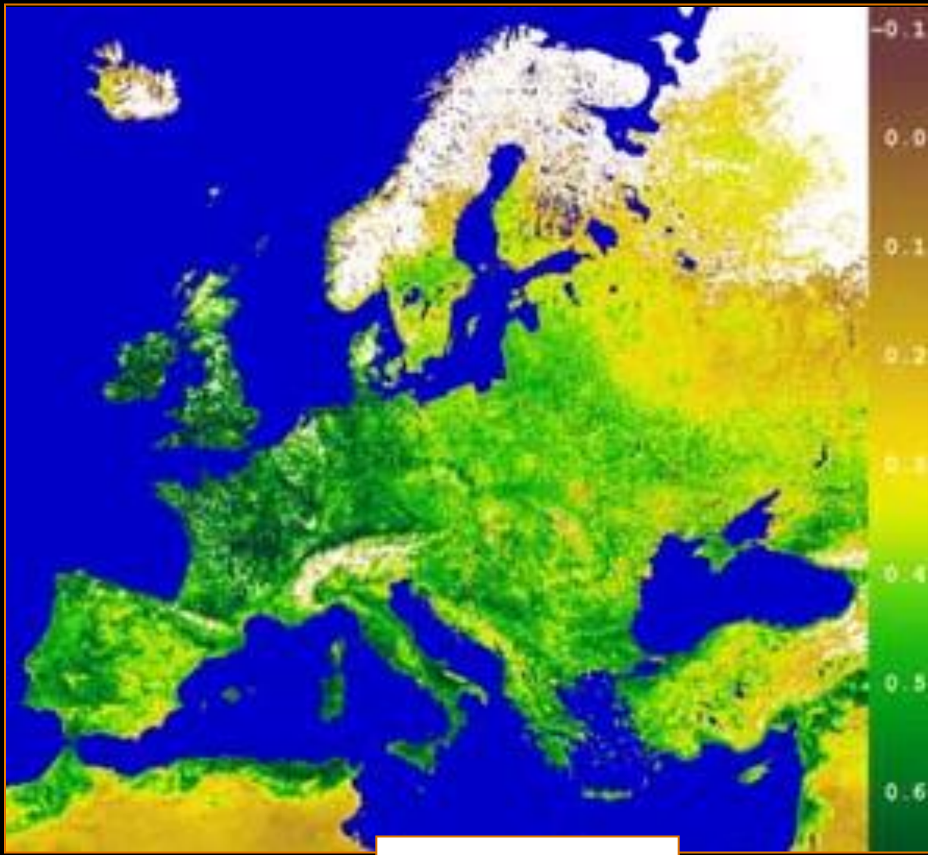
-1 NDVI 1

NDVI: provides information on PP, phenology

Vegetation Indices & NDVI

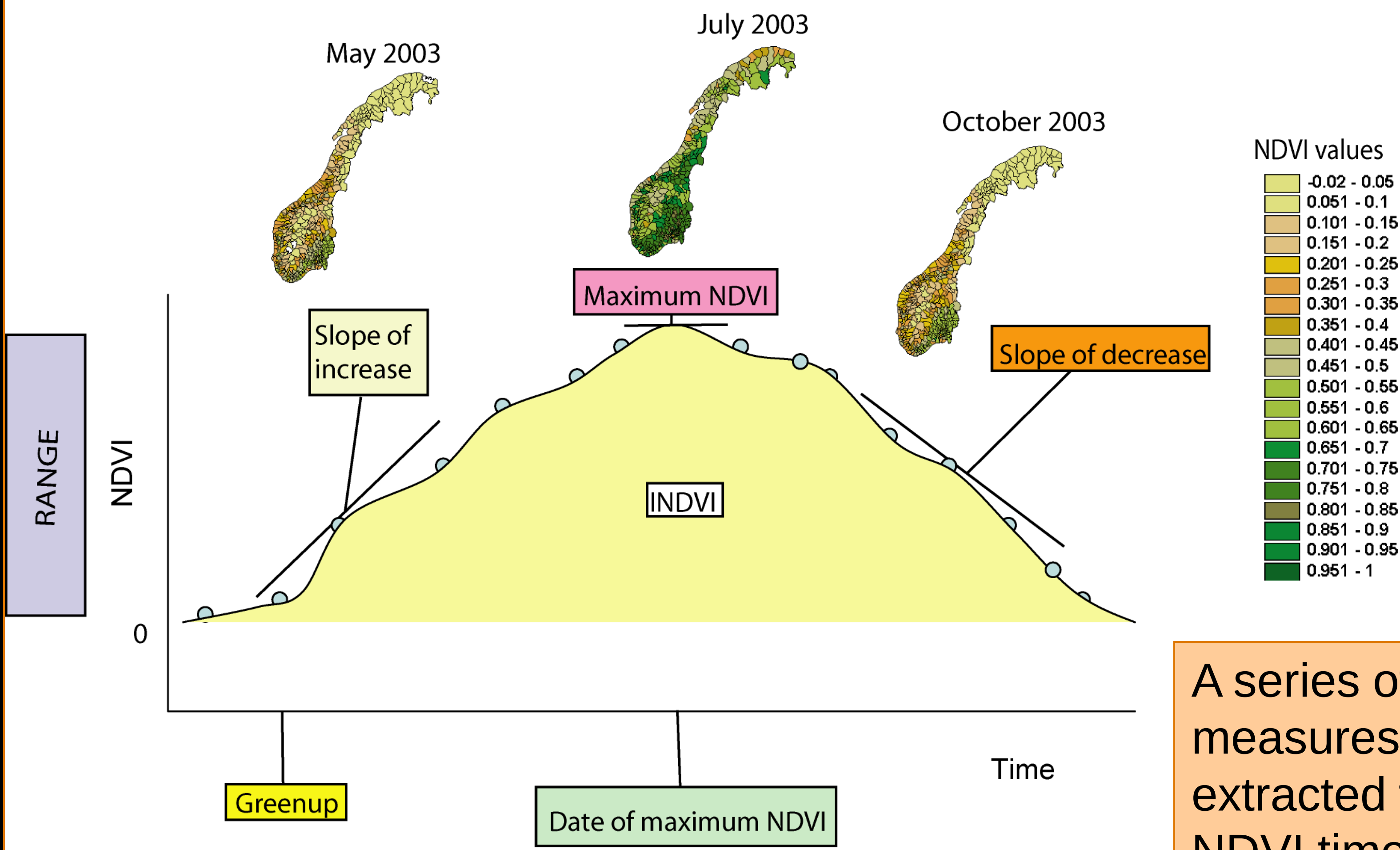
Several satellites allow NDVI monitoring. The most commonly used are:

- NOAA/AVHRR: since 1981; several datasets available from this source (GIMMS, PAL) with resolution varying from 1.1 to 8 km
- SeaWiFS: since 1997; from 1.1 to 4.5 km
- SPOT: since 1998; 1 km resolution
- MODIS: since 2000; from 1 km down to 250 m



NDVI, March

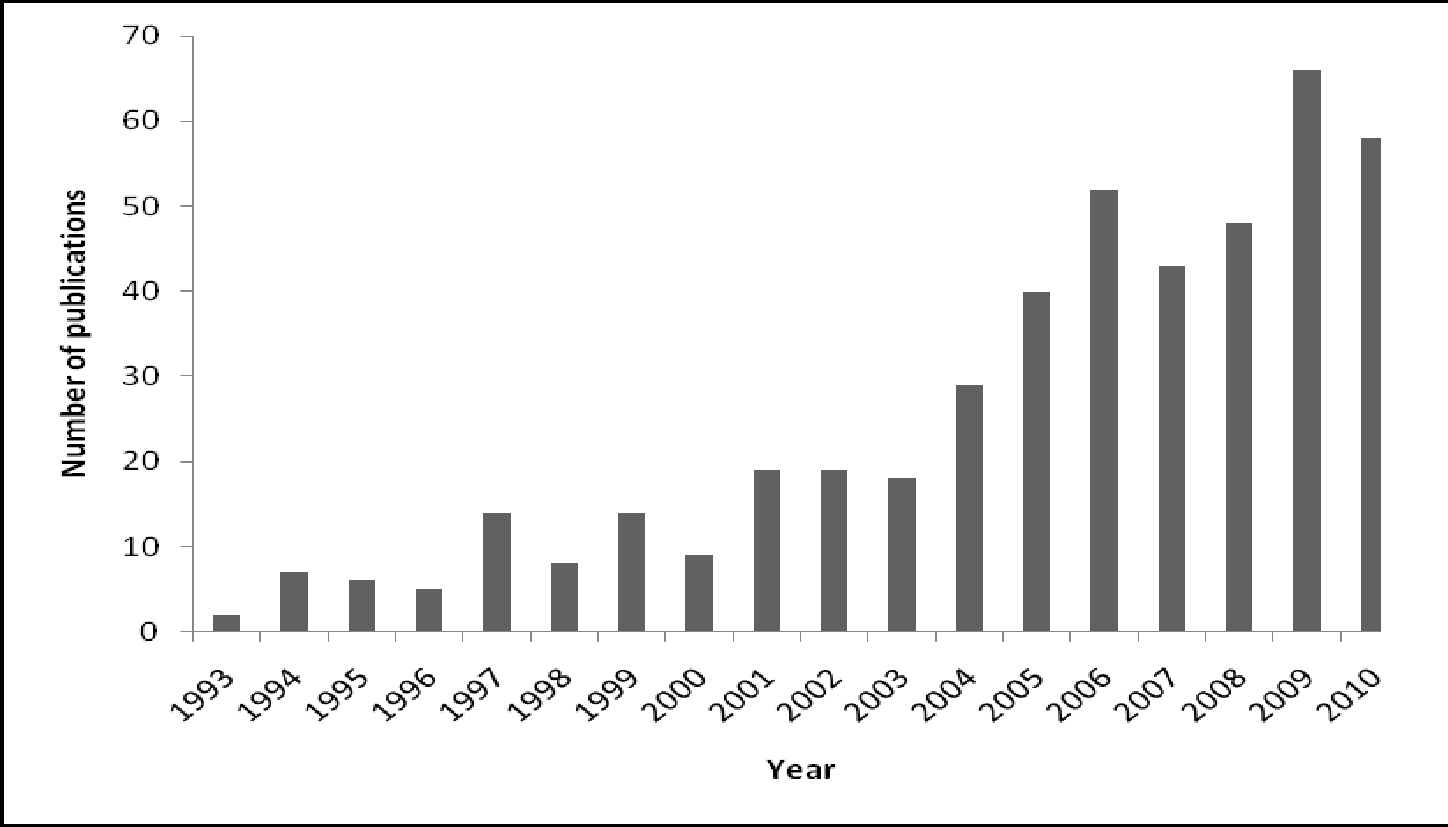
Vegetation Indices & NDVI



A series of measures can be extracted from NDVI time series

Pettorelli et al. (2005) TREE

NDVI: increasingly used in ecology

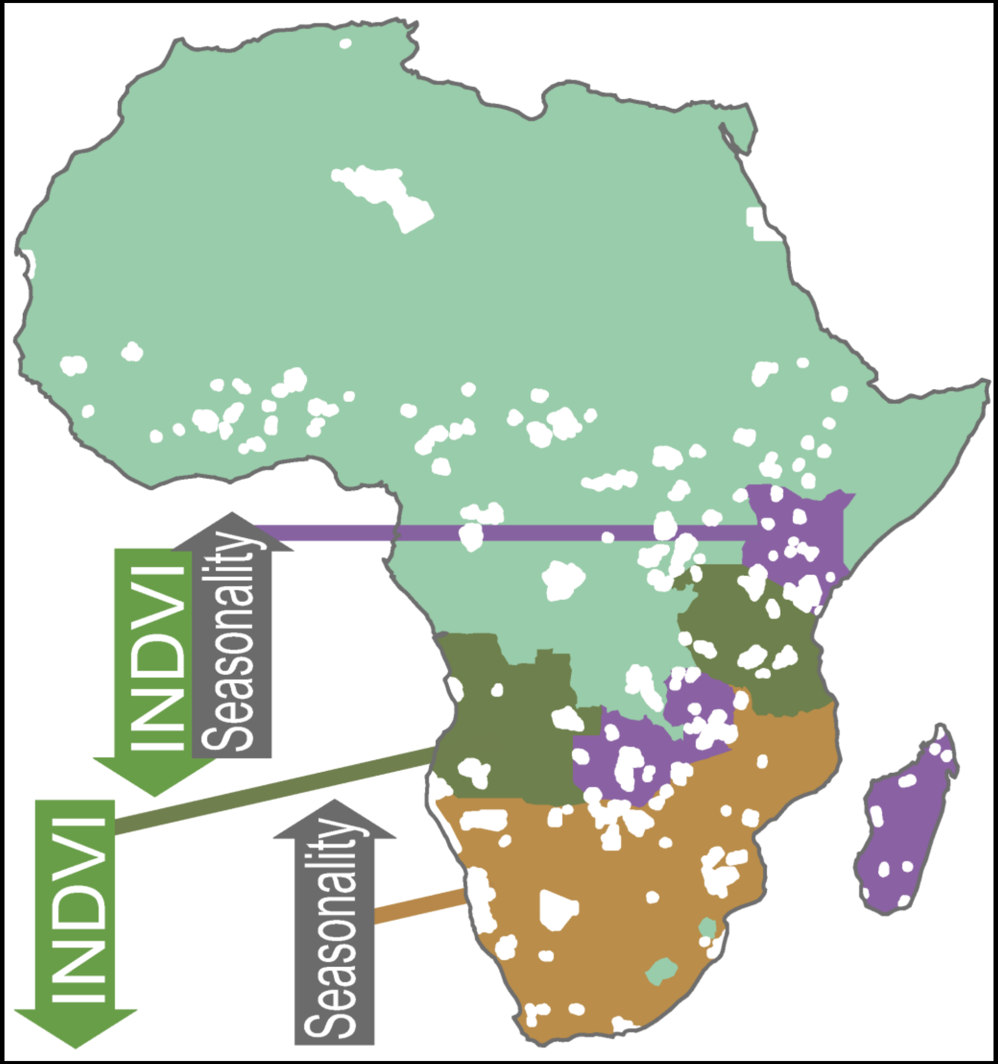


Pettorelli, in prep.

NDVI to track changes in ecosystem dynamics

- 168 protected areas (I and II), 1982-2008 NDVI dynamics analysed

→ results mostly supported current expectations regarding the impact of climate change in Africa

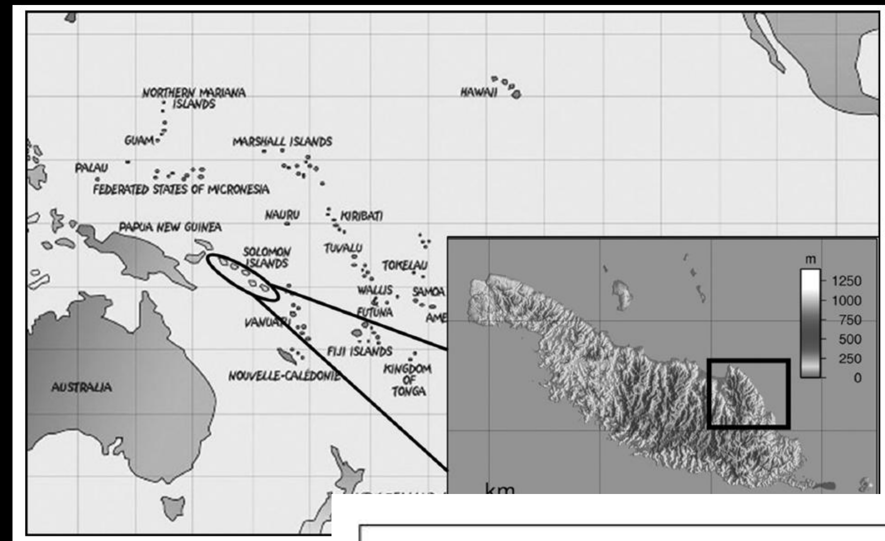


Pettorelli et al. (2012) Ecol. Ind.

NDVI to assess degradation

- Solomon Island, Makira

→ *informed patterns of degradation in a remote, biodiversity rich area*



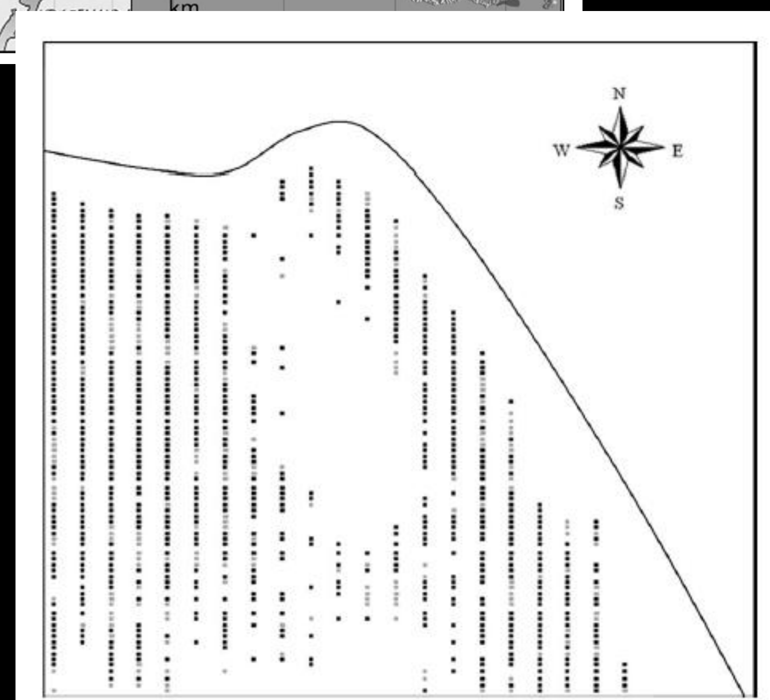


Figure 2 Average Spearman's rank correlation coefficient (r_s) between the year and the monthly average NDVI (April 2000–November 2008) for the 3229 MODIS pixels considered (area corresponds to square area delineated on Makira island in Fig. 1). Black squares (2660 pixels) represent pixels where the average correlation was negative, while grey squares (569 pixels) represent pixels where the average correlation was positive. Average negative

Garonna et al. (2009) Env. Cons.

Explaining ranging patterns in a lek-breeding antelope

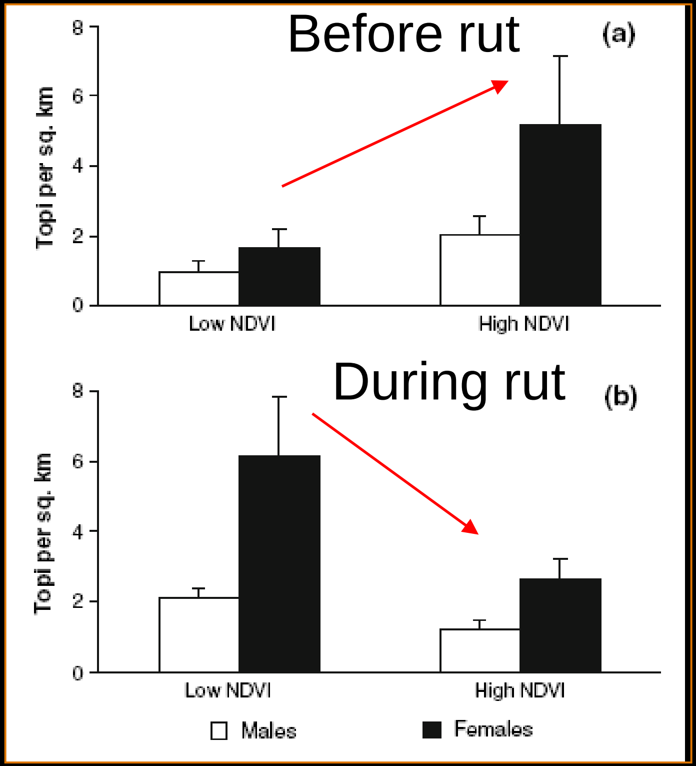
- Topi are medium-sized, grazing antelopes
- The male mating tactics include defense of larger resource based territories (up to 120 ha) and defense of smaller territories clustered on to resource-poor mating arenas or leks (down to 0.1 ha). Females are not territorial but range freely in unstable herds.
- Rut: during the wet season
- Study area considered: the Masai Mara (Kenya)

Brø-Jorgensen et al. (2008) Oecologia

Explaining ranging patterns in a lek-breeding antelope

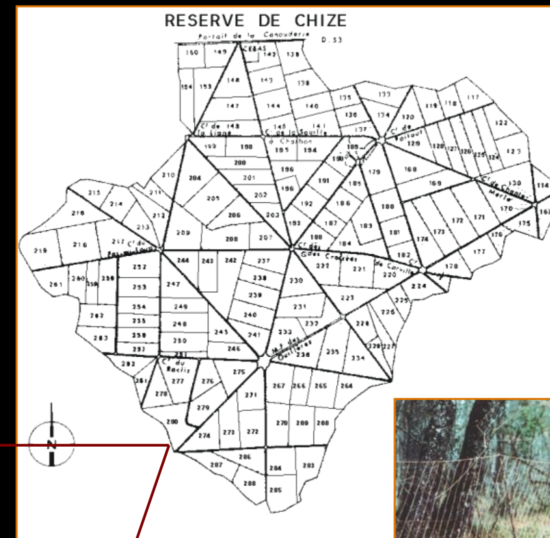
- Before the rut: positive selection by topi for greener pastures. The pattern is less pronounced in males (need for territorial attendance)

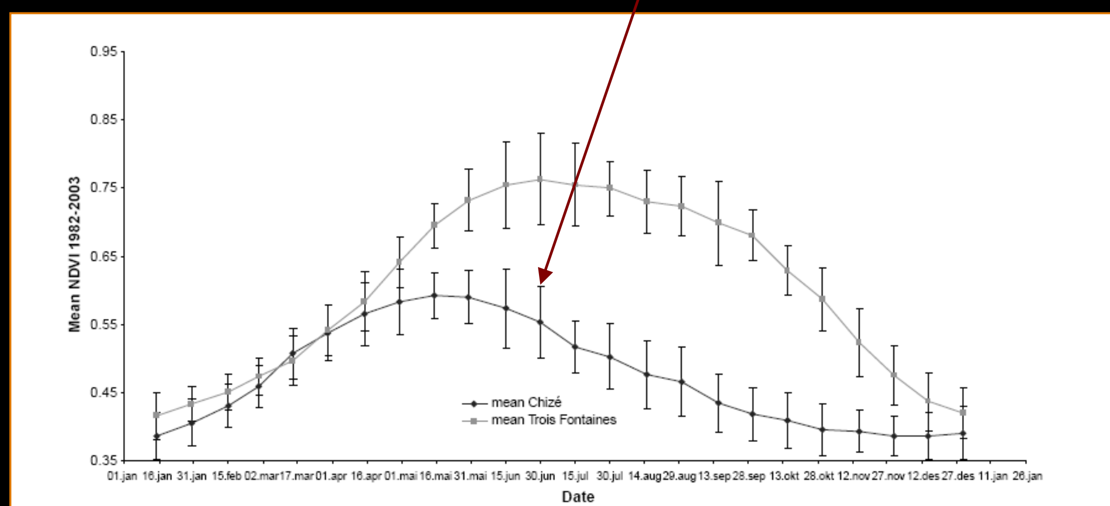
- During the rut: both male and female densities correlated negatively with NDVI →At this time, resources are generally plentiful and distribution is determined by benefits of aggregating on resource-poor territories for mating



Brø-Jorgensen et al. (2008) Oecologia

Identifying the key periods influencing the future individual performance



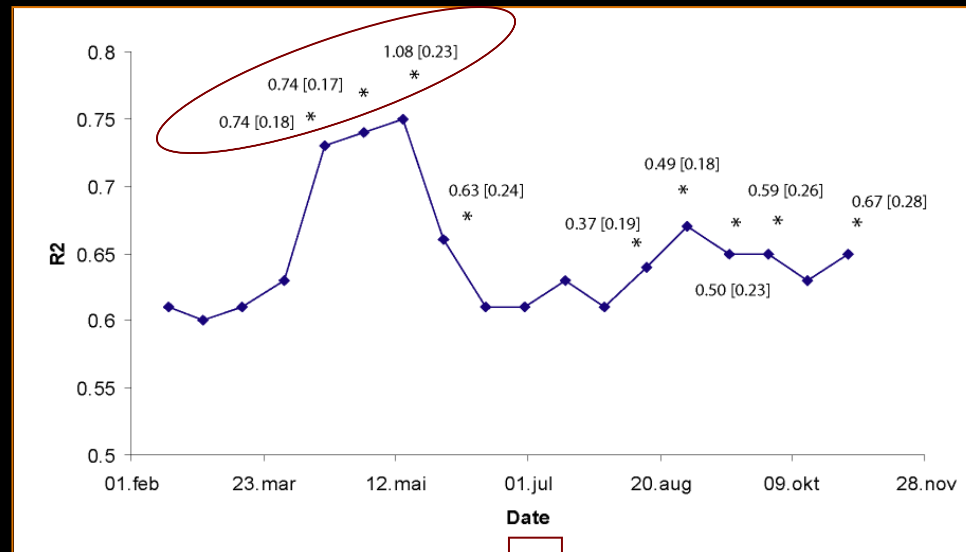


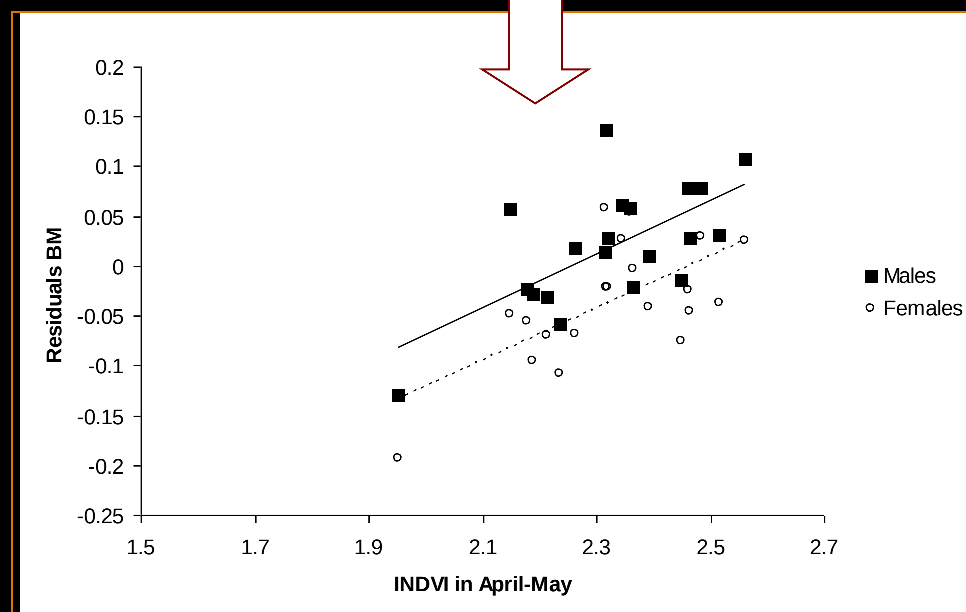
Pettorelli et al. (2006) Oikos

NDVI to identify key periods

Identifying the key periods influencing the future individual performance

Correlation BM/NDVI





→ *Knowing the vegetation conditions in spring helps predict body mass of fawns in winter*

Pettorelli et al. (2006) Oikos

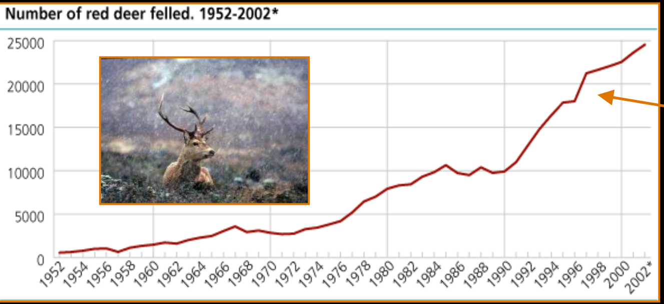
Quantification of the direct and indirect effects of climate on animal populations

ZSL

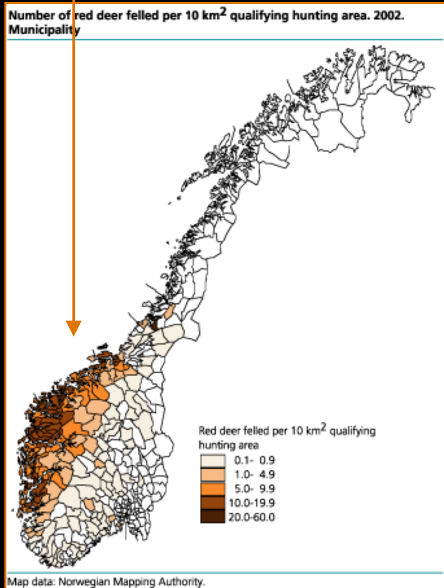
summer

winter

Distribution area, in expansion

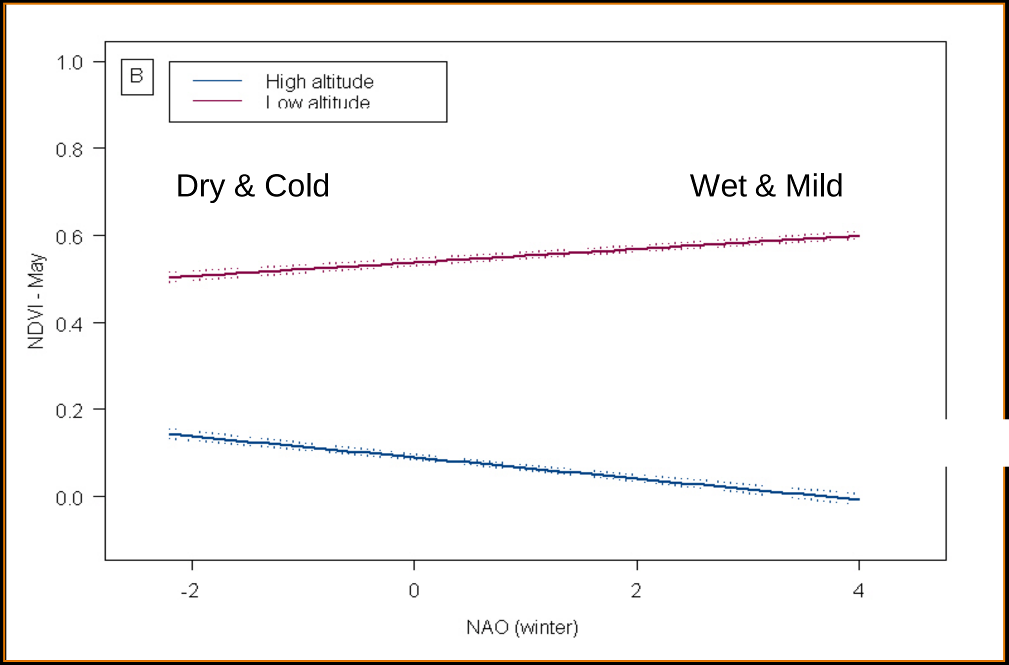


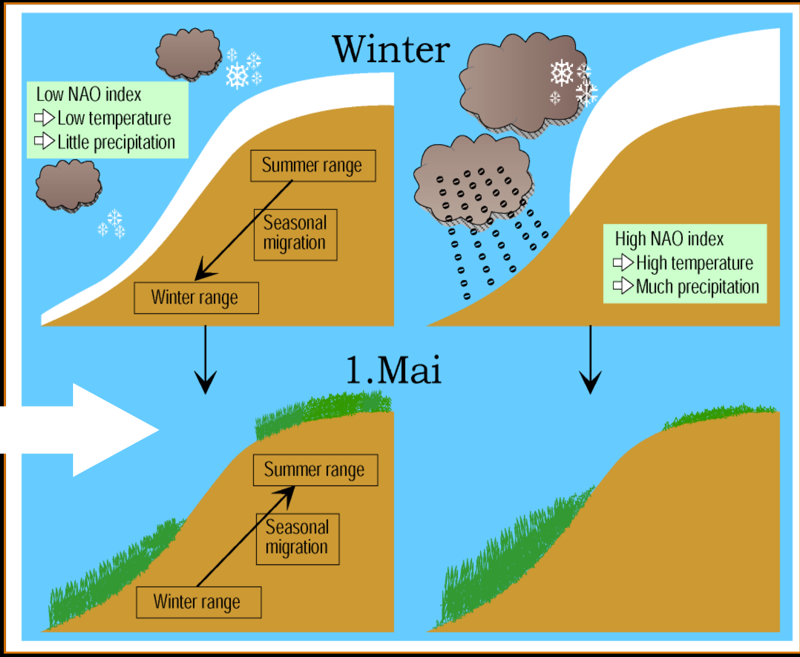
Constant augmentation of the number of individuals harvested



Pettorelli et al. (2005) Proc. Roy. Soc. (B)

Link between the climatic conditions and the vegetation onset

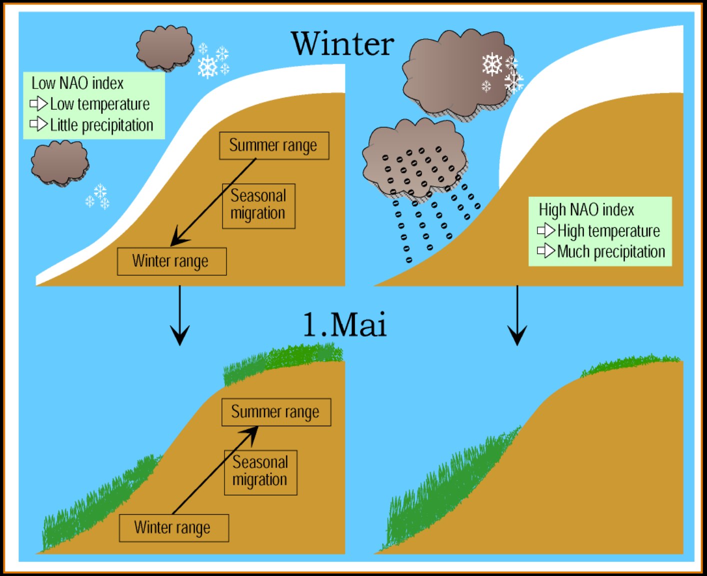


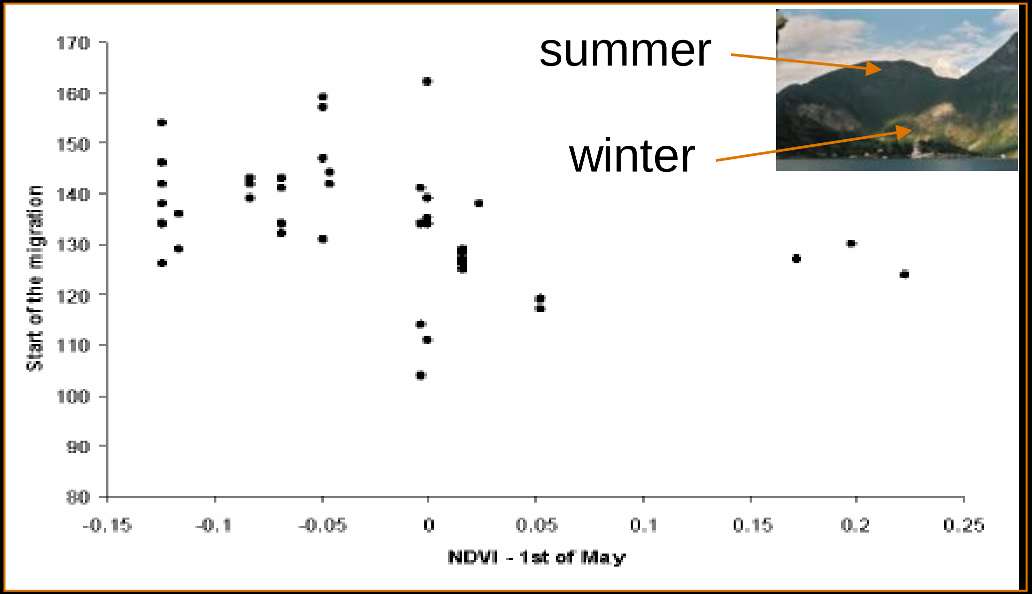


Interaction between altitude and the climatic conditions in winter (NAOw) on the determination of the vegetation onset

Pettorelli et al. (2005) Proc. Roy. Soc. (B)

Impact on red deer seasonal migration patterns





Advanced migration with an earlier start of the vegetation (up to 20 days)

→ The vegetation conditions in the winter area determine the starting date of the seasonal migration

Pettorelli et al. (2005) Proc. Roy. Soc. (B)

Impact on red deer body masses

Positive impact of an early vegetation onset on red deer body masses in autumn (up to 5Kg difference)

→

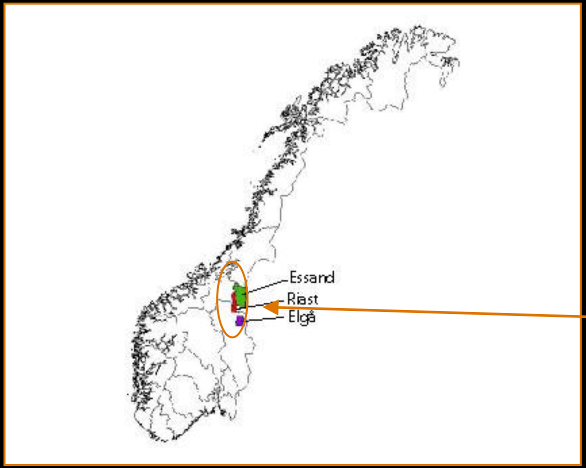
1 kg: 0.07 increase in the proportion of primiparous females that ovulate

1 kg: 0.13 increase in the proportion of female fawns that survive

Pettorelli et al. (2005) Proc. Roy. Soc. (B)

NDVI to quantify the direct and indirect effects of climate on animal populations

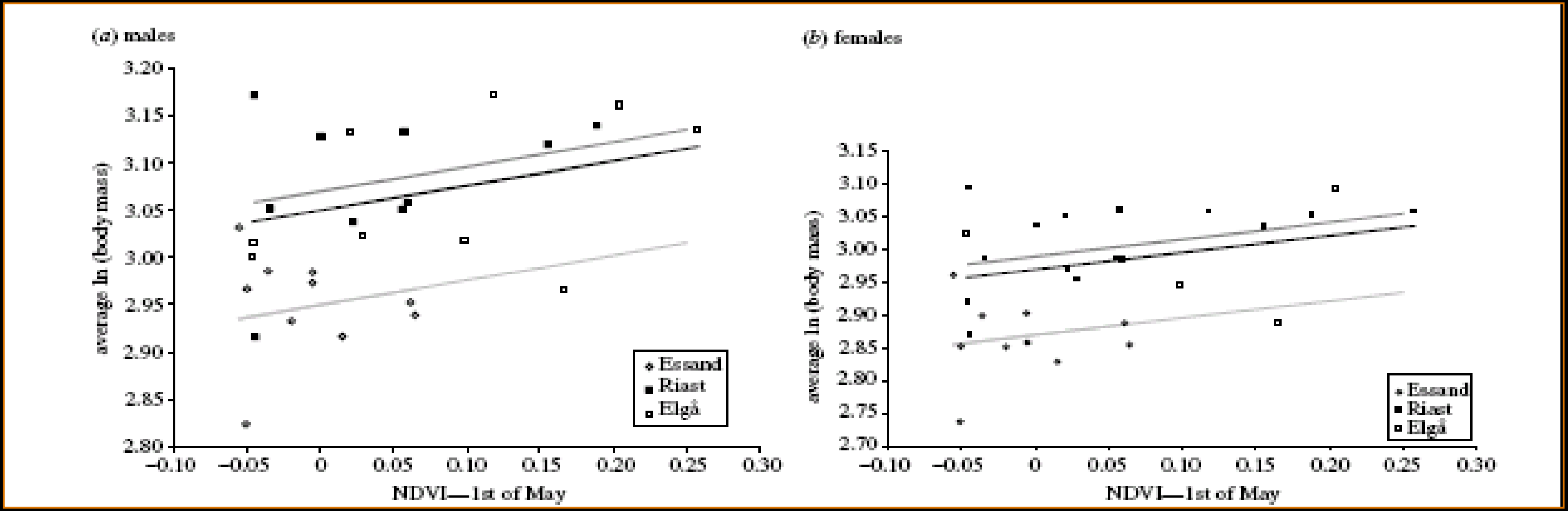
→ Do we also observe an effect of the vegetation onset on reindeer body masses?



3 populations, more than 1800 individuals (calves)

Pettorelli et al. (2005) Biol. Letters

NDVI to quantify the direct and indirect effects of climate on animal populations



→Yepp: Positive effect of the vegetation onset on the body masses of reindeer calves (2 Kg)

Pettorelli et al. (2005) Biol. Letters

NDVI to quantify the direct and indirect effects of climate on animal populations

ZSL

		
NDVI – 1er May **Trend**	**Going Up (earlier vegetation onset at low altitude)**	**Going Down (later vegetation onset at high altitude)**
NDVI – 1er May **Effect on BM**	**Positive**	**Positive**
Future	**Good? (for the moment)**	**Bad? (for the moment)**

NDVI to quantify the link between energy availability and density estimates

- 13 antelope species, 77 National Parks, 23 countries

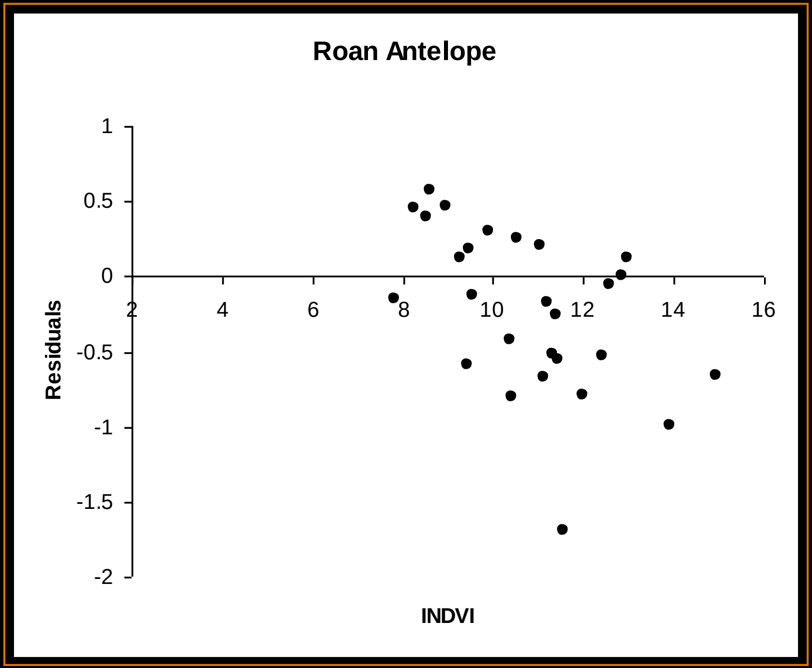
→ *NDVI positively linked to antelope abundance in Africa*

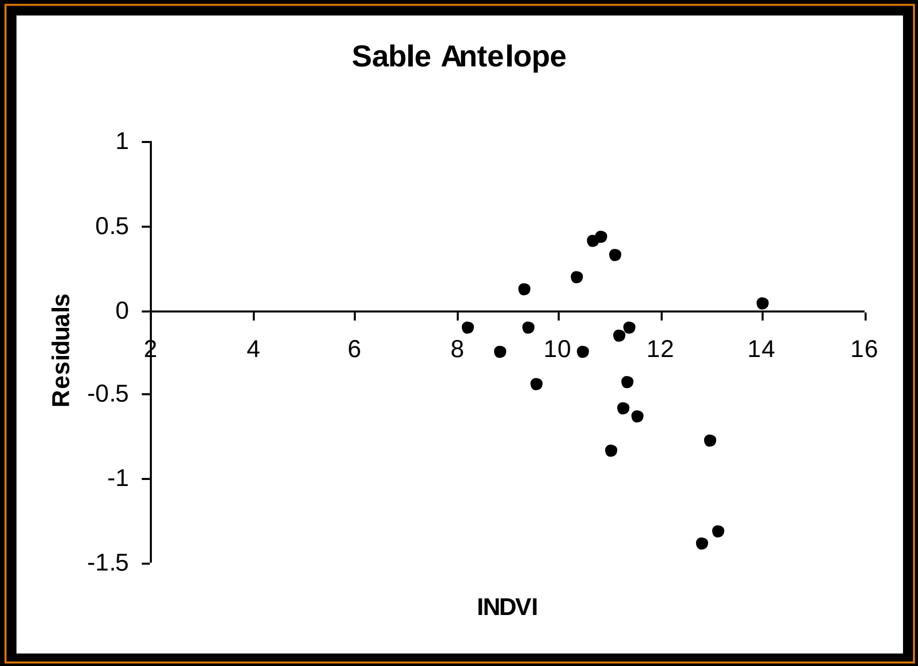
→ *Better correlation for certain species than for others*

- Same results recently for savannah elephants

Pettorelli et al. (2009) Am. Nat.; Duffy & Pettorelli (2012) Afr. J. Ecol.

NDVI to quantify the link between energy availability and density estimates



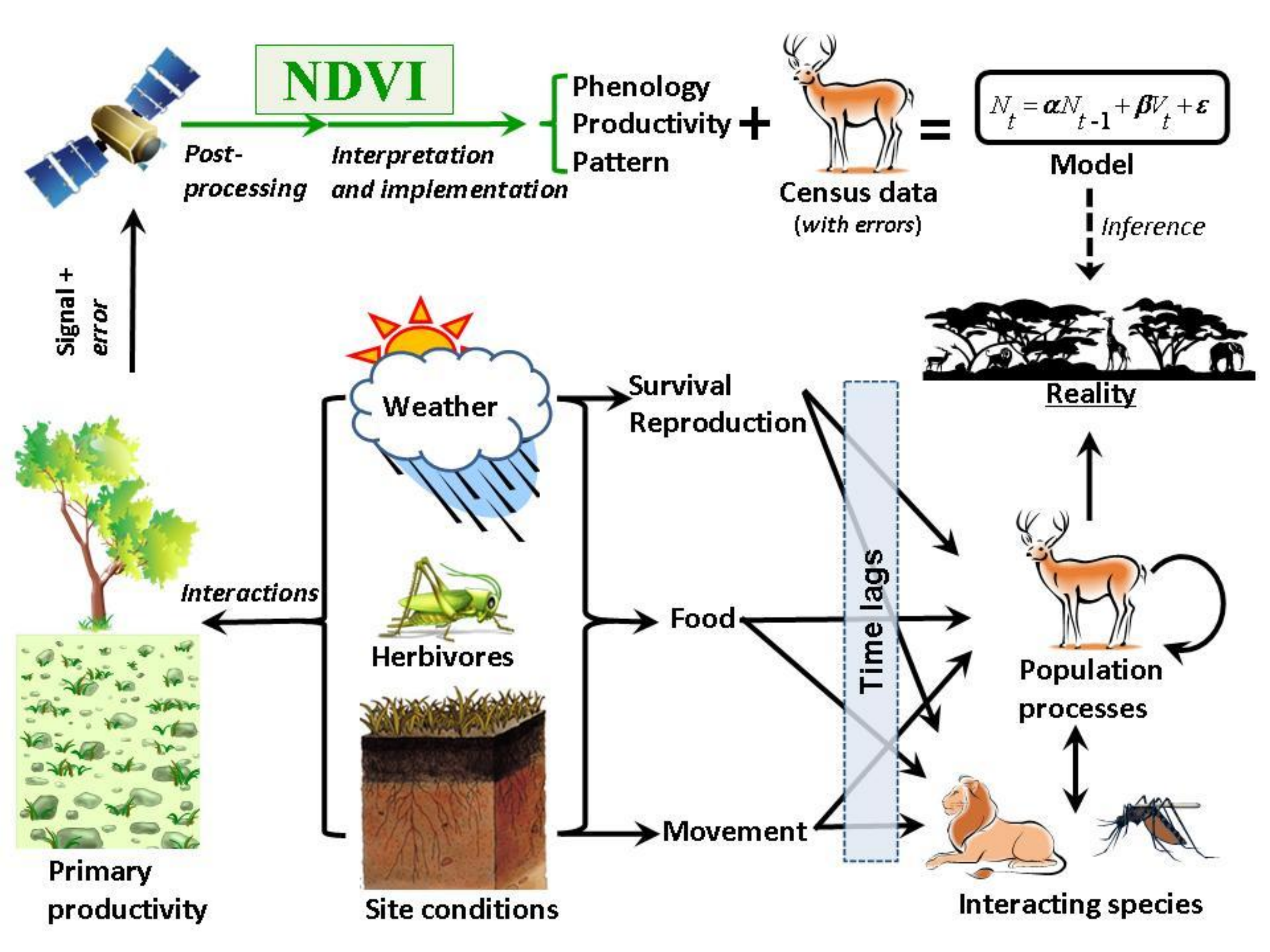


NDVI is a tool with high potential in terrestrial ecology

QUESTION	SPECIES	REFERENCES
NDVI dynamics and space use	Brown bears Vervet monkeys Mongolian gazelles Ptarmigans African buffalo	Wiegand et al. 2008 Willems et al. 2009 Mueller et al. 2008 Pedersen et al. 2007 Winnie et al. 2008
NDVI dynamics and migration patterns	Wildebeest Marsh harriers Saiga antelope	Boone et al. 2006 Klaassen et al. 2010 Singh et al. 2010
NDVI dynamics and demographic parameters	Moose Elephants African buffalo	Herfindal et al. 2006 Rasmussen et al. 2006 Ryan 2006
NDVI and population dynamics	Rodents Elephants	Kausrud et al. 2007 Trimble et al. 2009

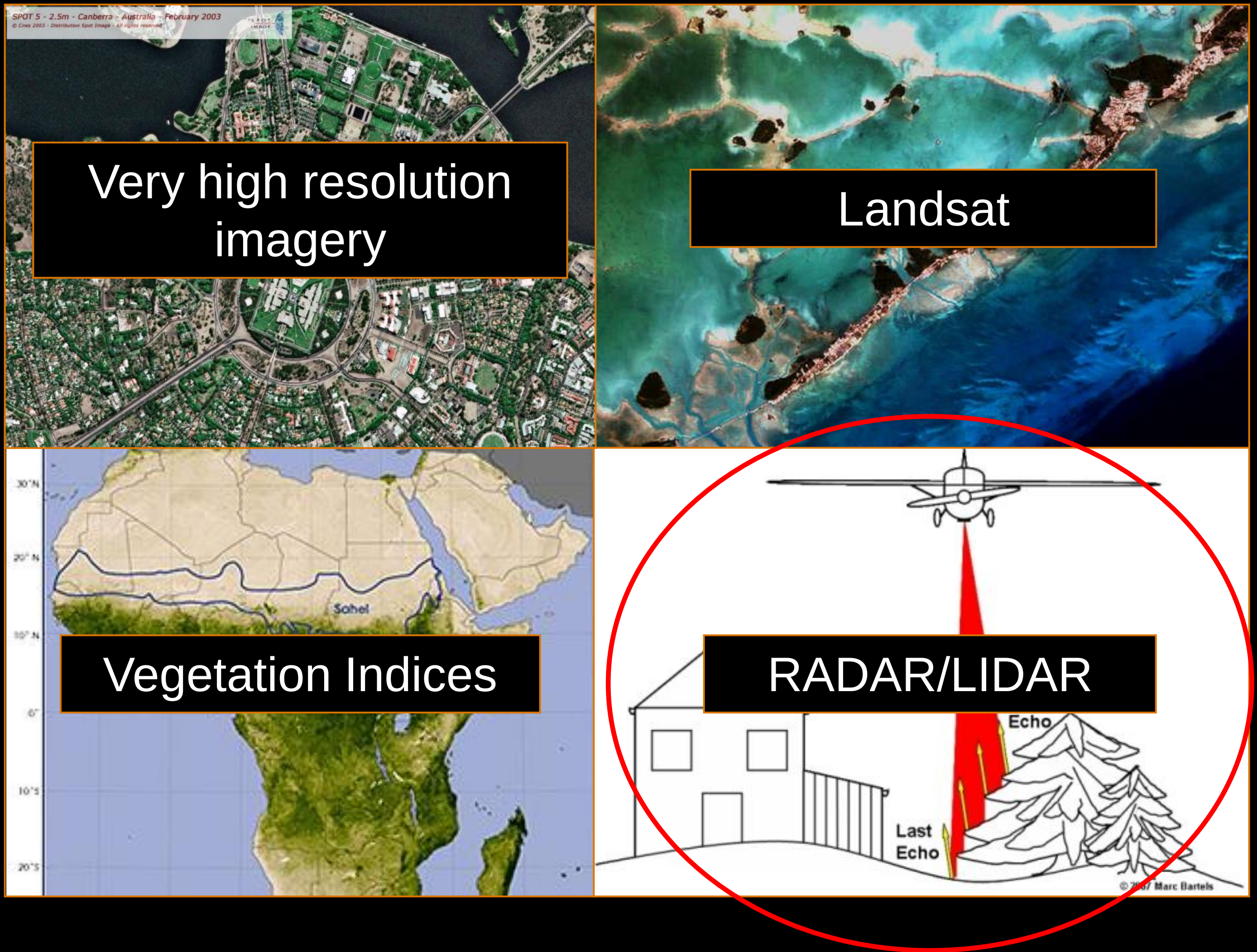
GROUP	PARAMETER	LOCATION
Invertebrates	Habitat use	Africa
Invertebrates	condition	Australia
Invertebrates	Abundance	Central Arizona
Invertebrates	Species richness	Australia
Birds	Habitat use	Spain
Birds	Breeding success	Mediterranean region
Birds	Annual survival	Eastern Sahel
Birds	Abundance	North America
Birds	Species richness	North America
Rodents	Abundance	Argentina
Primates	Habitat use	South Africa
Primates	Condition	Namibia
Primates	Abundance	Brazil
Ungulates	Habitat use	Svalbard
Ungulates	Body mass	France
Ungulates	Annual survival	Canada
Ungulates	Abundance	Africa
Ungulates	Species richness	Tanzania
Carnivores	Habitat use	Norway

NDVI is a tool with high potential in terrestrial ecology



Pettorelli et al. (2011) Clim. Res.

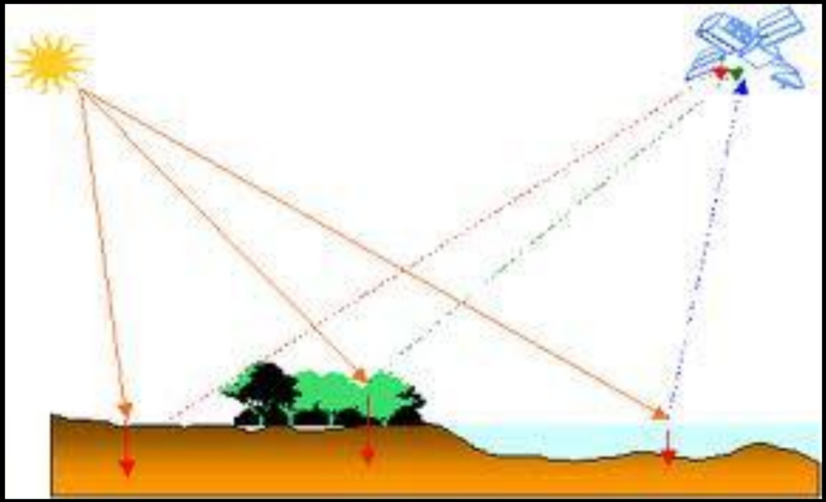
How can remote sensing help ecologists?

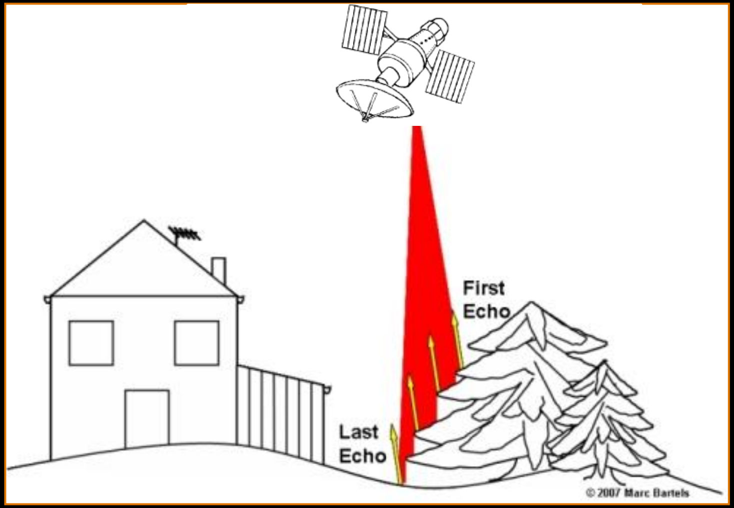


Not all satellites are equal

PASSIVE SENSORS

ACTIVE SENSORS





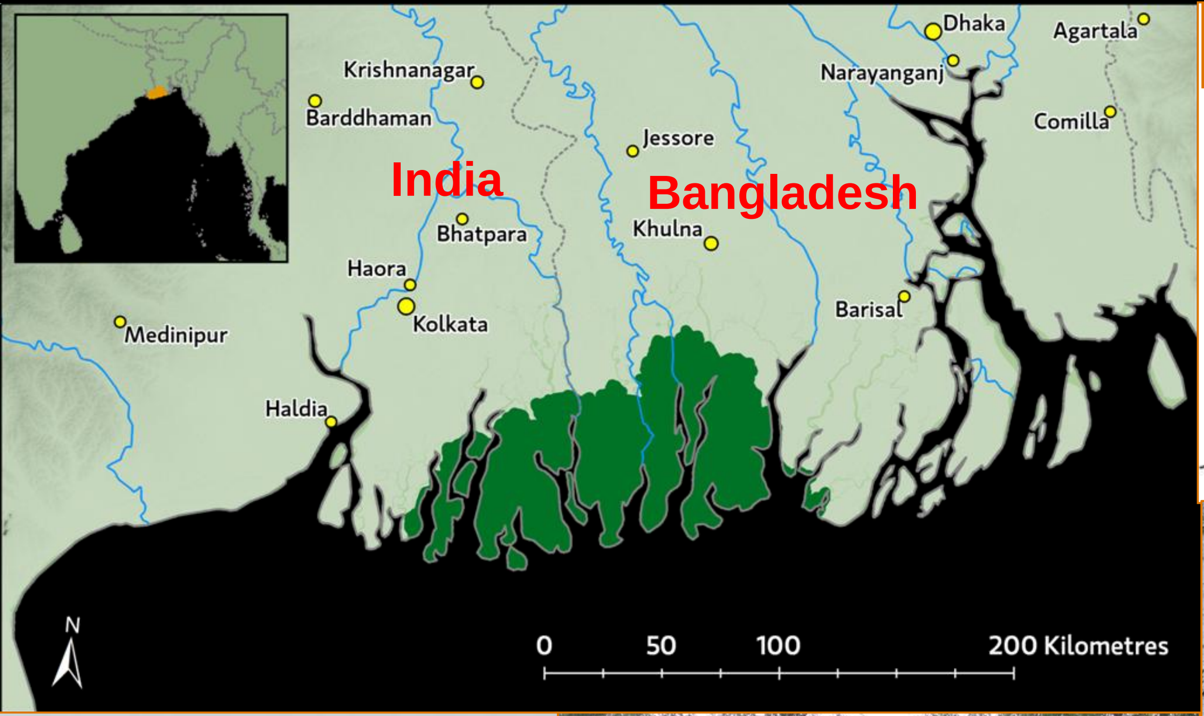
LANDSAT

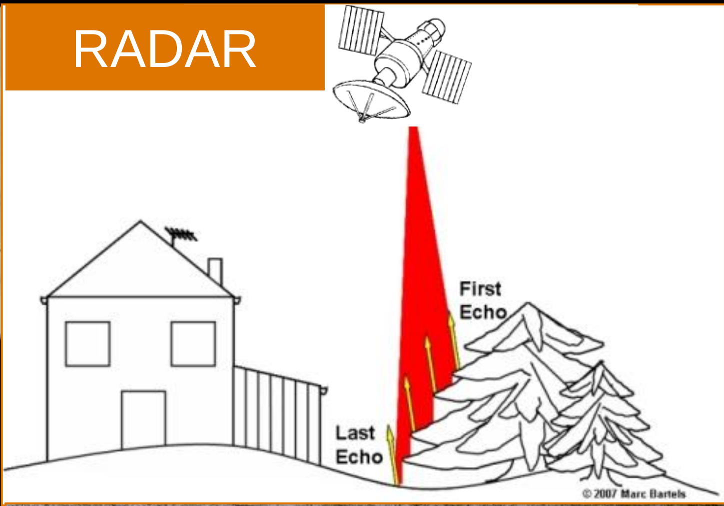
MODIS

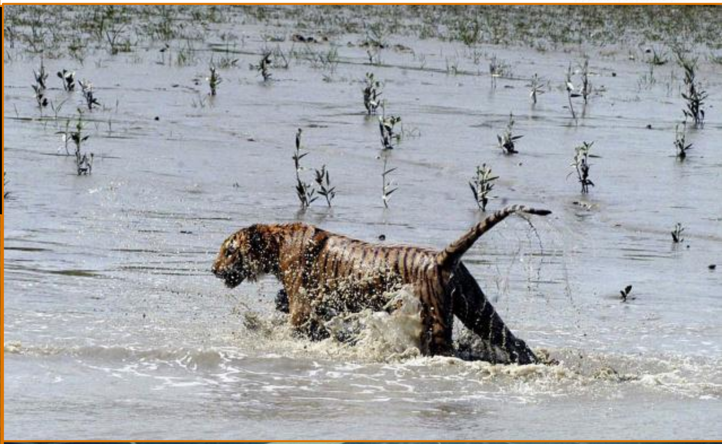
RADAR

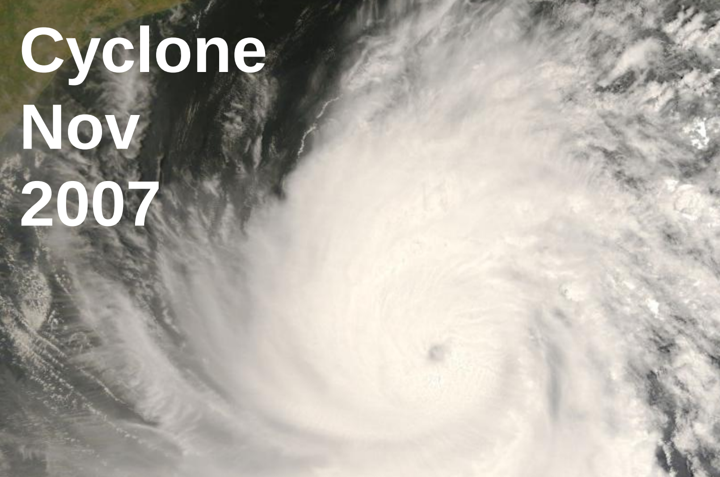
LIDAR

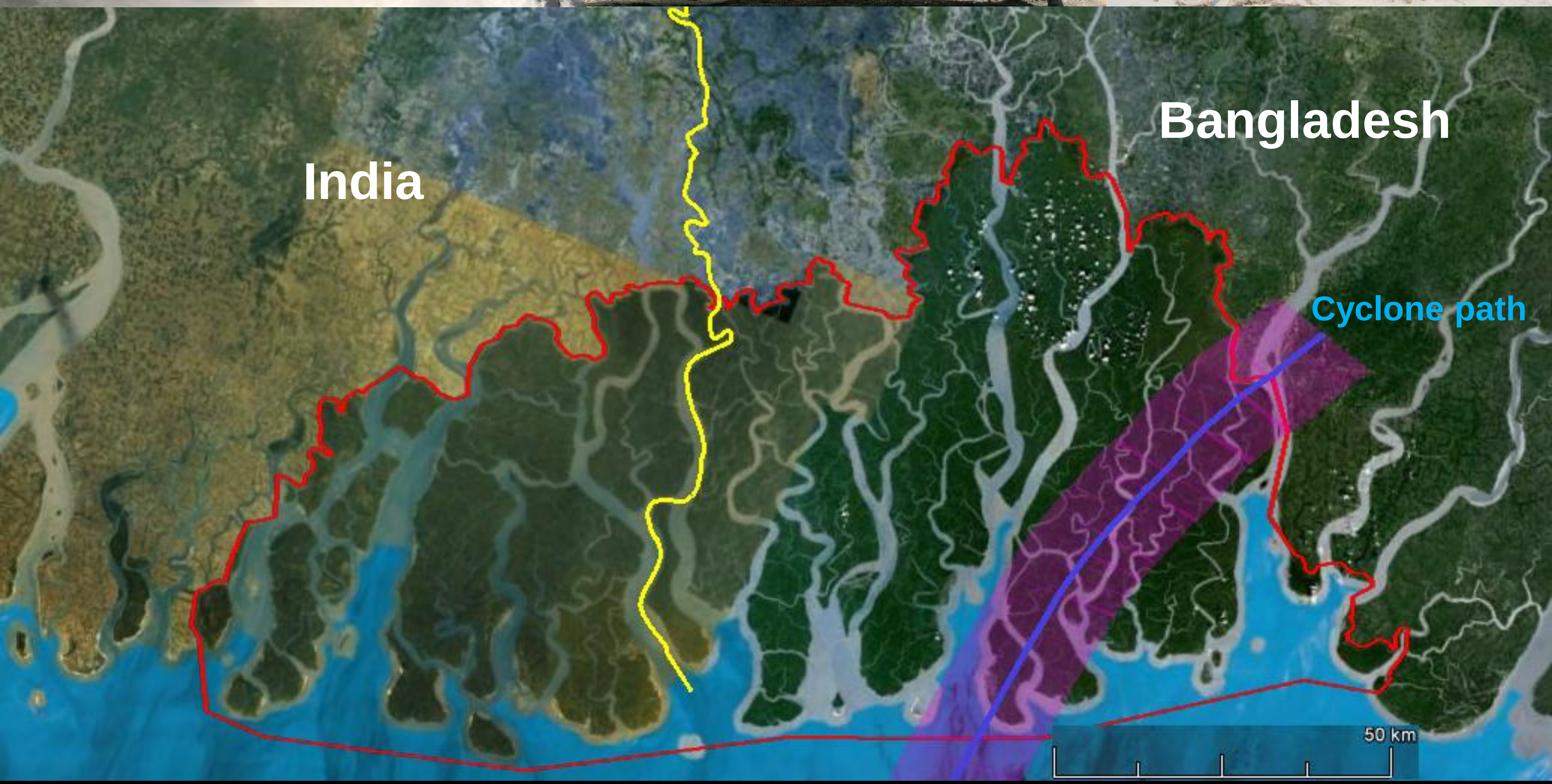
Mangrove degradation assessment

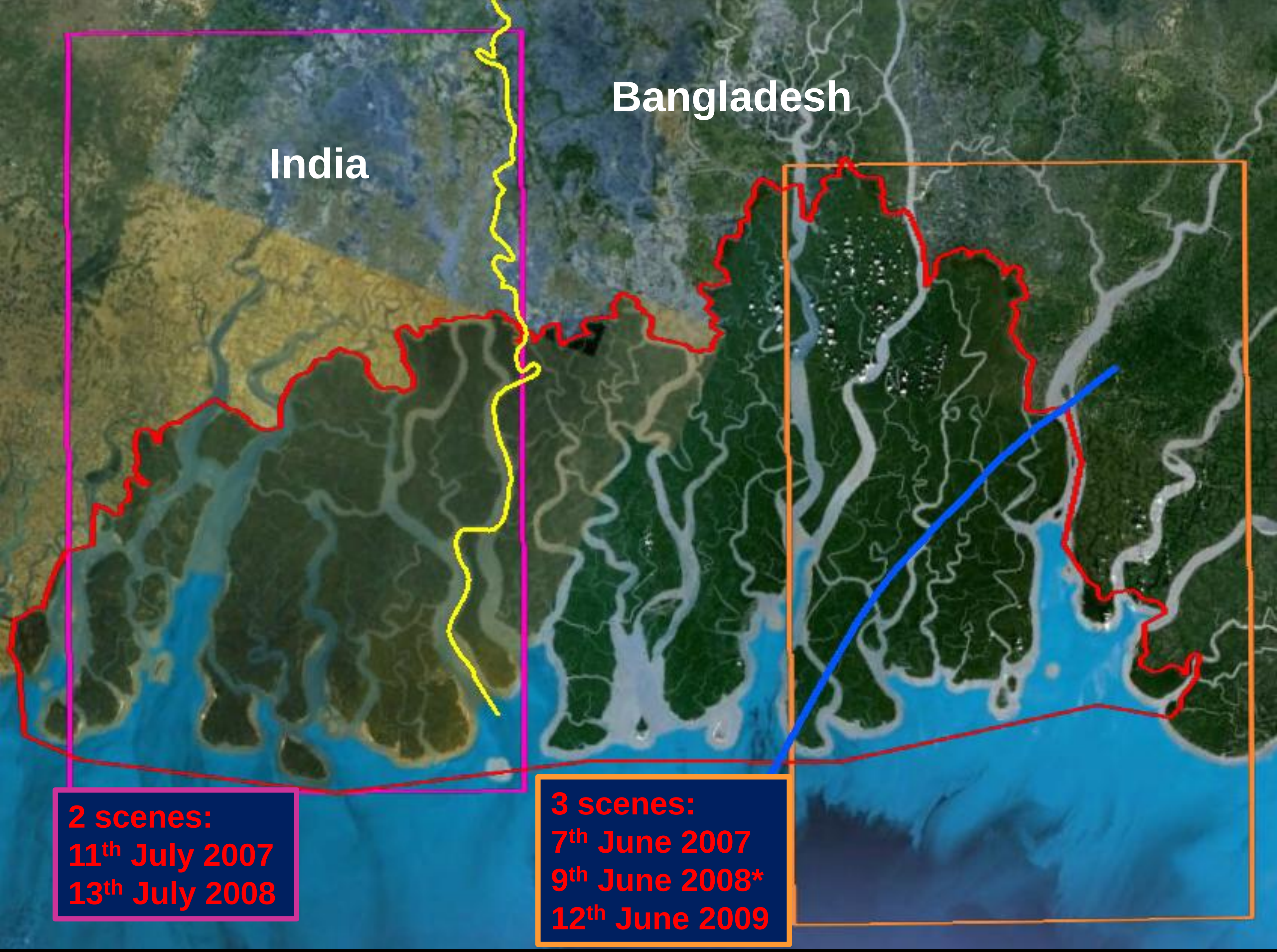






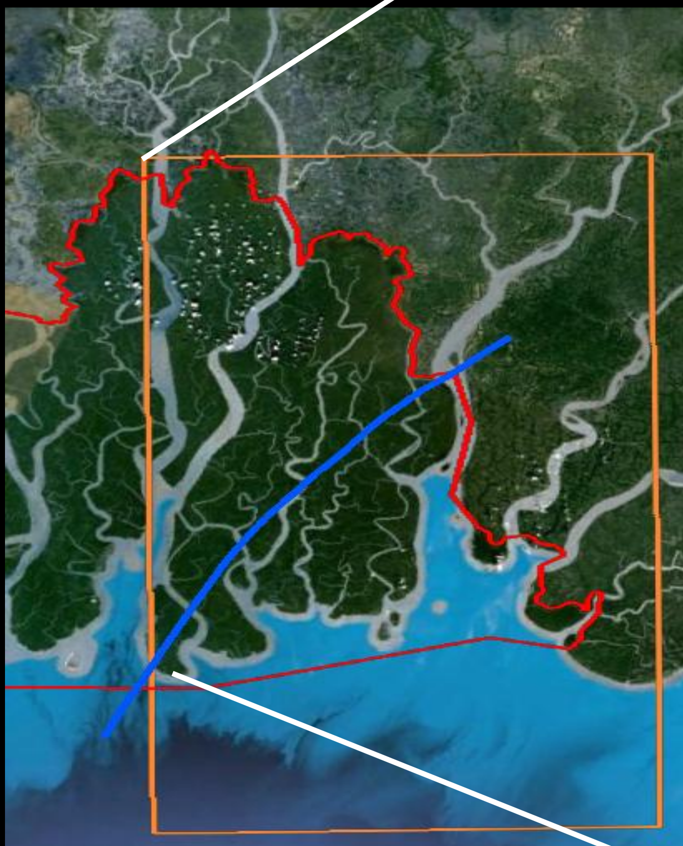

Cyclone
Nov
2007


Bangladesh
India
Cyclone path
50 km

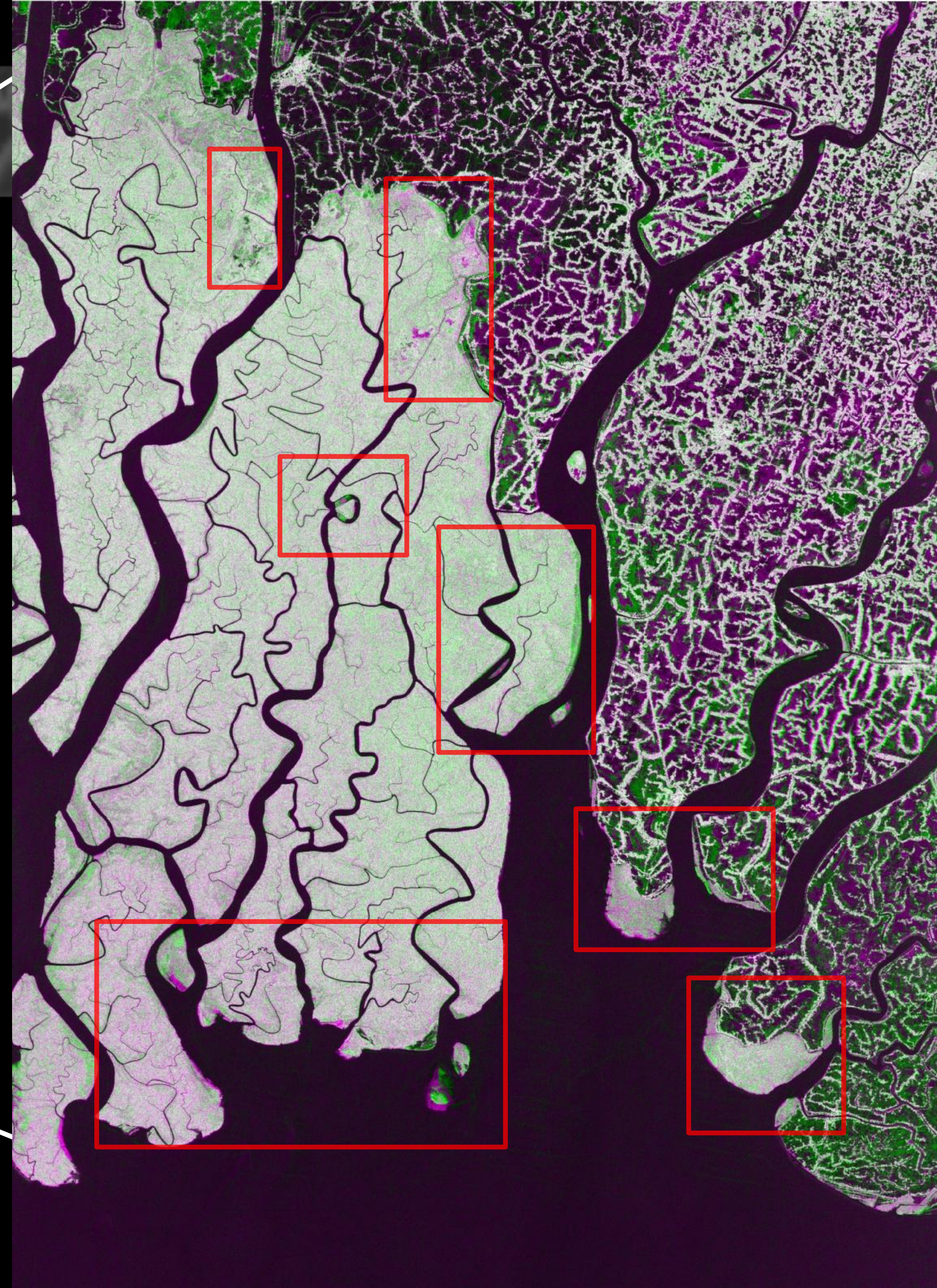


Bangladesh
India
2 scenes:
11th July 2007
13th July 2008
3 scenes:
7th June 2007
9th June 2008*
12th June 2009

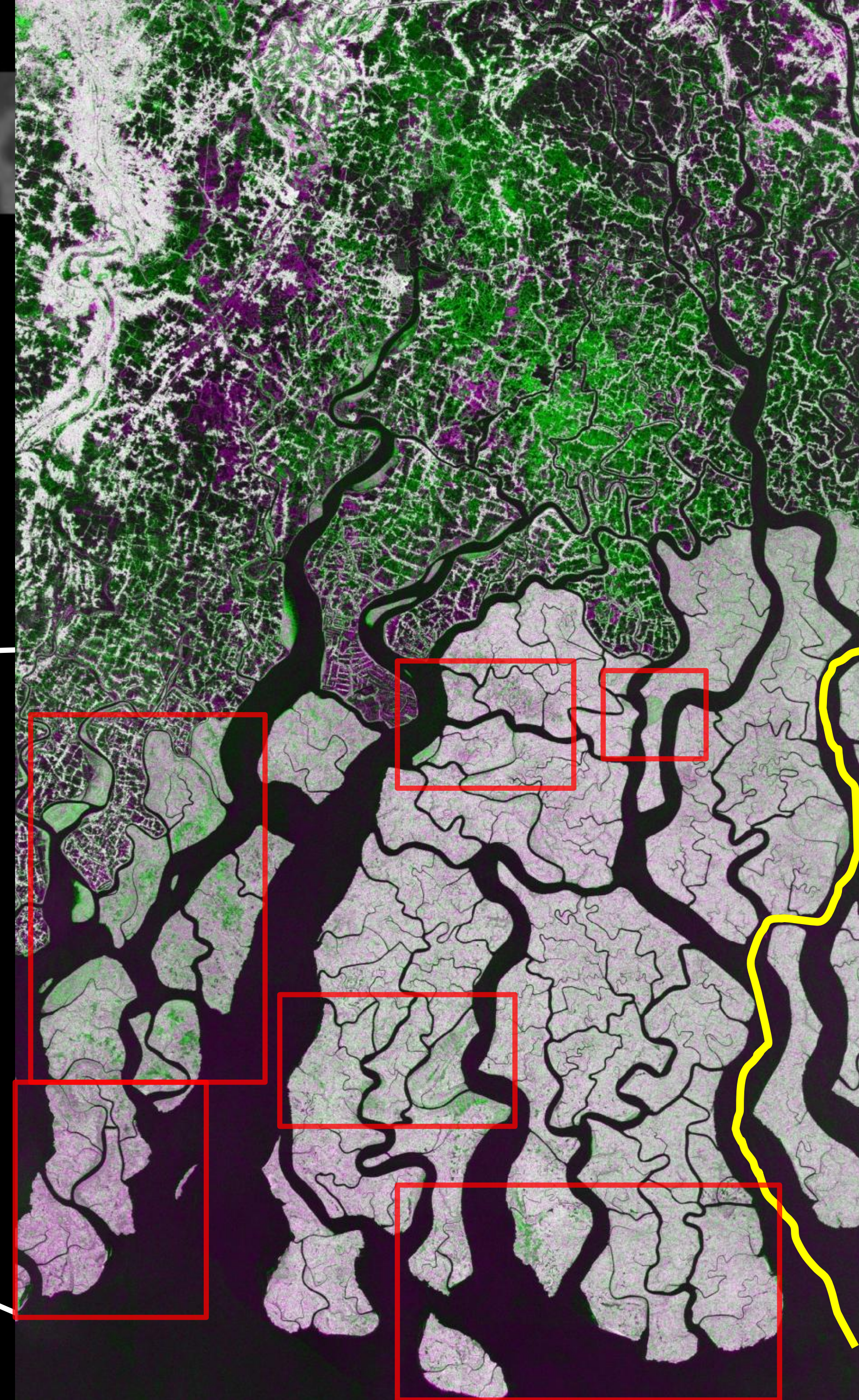
Purple: decreased vegetation
Green: increased vegetation
Darker patches: overall lower vegetation



East Sundarbans, Bangladesh
June 2007 – June 2009



Purple: decreased vegetation
Green: increased vegetation
Darker patches: overall lower vegetation



West Sundarbans, India
July 2007 – July 2008

What did we learn?

- Changes can occur really rapidly! High level of spatial heterogeneity in changes
- Higher level of average degradation in the Indian side
- Fast rate of coastal degradation, especially in Bangladesh
- High degradation in the North of the Bangladeshi side
- Sporadically distributed signs of improvement, especially in India

LiDAR and species richness

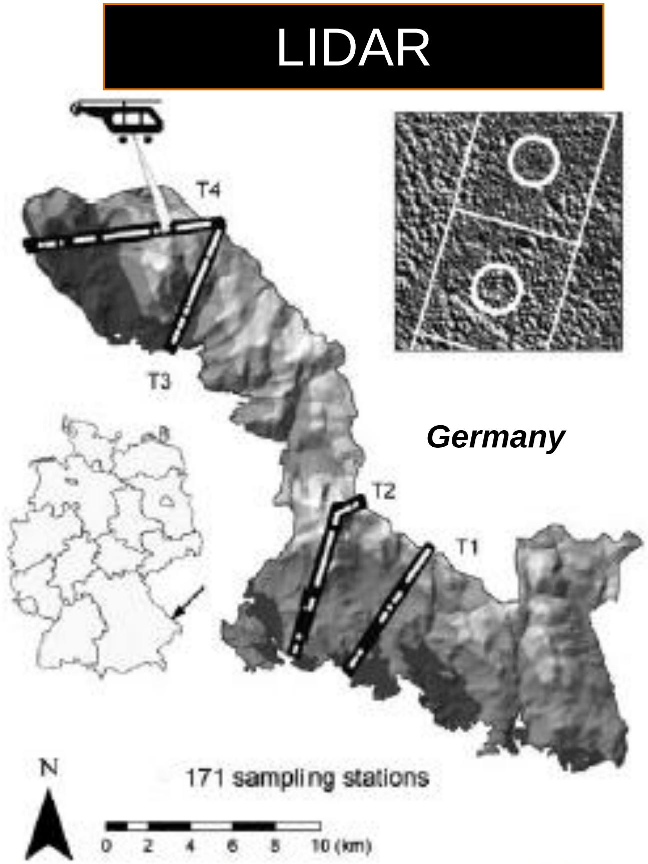


Fig. 1. Study area and sampled transects T1–T4. The map of Germany shows the location of the National Park. The map of the park shows the topography with low (dark) to high (pale) elevations. The 171 sampling stations are shown as white dots. The inset at the top shows an example of the digital surface model generated by LiDAR, with 0·1 ha circles and 1·0 ha squares.

Table 1. Partitioning of the explained variance for the three data sets of predictors: LiDAR, biotic and abiotic

	Pitfall traps					Flight-interception traps				
	Total R^2	Total 95% CI	LiDAR R^2	Biotic R^2	Abiotic R^2	Total R^2	Total 95% CI	LiDAR R^2	Biotic R^2	Abiotic R^2
Individuals	8·9	−0·3 to 19·9	17·7	−8·0	54·2	43·8	30·5–55·7	99·8	75·8	54·8
Richness	3·0	−8·7 to 10·7	99·5	99·0	5·9	26·4	13·6–39·4	89·1	30·1	48·4
Diversity (Simpson)	3·7	−6·5 to 19·8	99·0	54·3	−25·7	23·8	14·3–34·0	94·8	60·5	66·5
Body size	27·1	14·3–39·6	87·6	60·6	19·0	14·7	3·9–27·2	66·8	31·0	14·0

For the total explained variance, the 95% confidence intervals (CI) based on bootstraps are given. Note, that 'varpart'-functions frequently give negative estimates of variation. We give the adjusted R^2, which adjusts the number of explanatory terms in a model. Adjusted R^2 can be negative for any fraction, while unadjusted R^2 of testable fractions will always be non-negative (Oksanen *et al.* 2006). Such negative values indicate variability in the data large enough to produce a negative estimate, even though the true value is zero or positive. LiDAR, light detection and ranging.

Muller & Brandl 2009 J.Appl.Ecol.

Remote sensing & biodiversity monitoring

- RS provides a fantastic opportunity to monitor changes in habitat distribution (e.g., ice sheet cover change, deforestation rate), habitat degradation, land use change, habitat fragmentation
- It can also help gather information on changes in functional attributes of habitats and ecosystems (e.g., phenological change, changes in primary productivity, in frequency of fire)
- RS can provide a quantified measure of change which can be linked to biodiversity, but also to behaviours, life history traits or abundance




Limitations & considerations

- Choosing which sensor and which resolution: scale issue, quality issue, budget issue
- Trade-off between spatial and temporal resolution
- Usefulness might be a function of the scale, the question and the biological model considered
- Consistency and commitment needed to insure long-term product availability
- RS community and wildlife management in need of more collaboration to ensure that pertinent tools are developed and that money is not wasted




Thanks!