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Applications of GIS and Remote Sensing to Evolution, Ecology, and Biodiversity Conservation

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RGGS 2020

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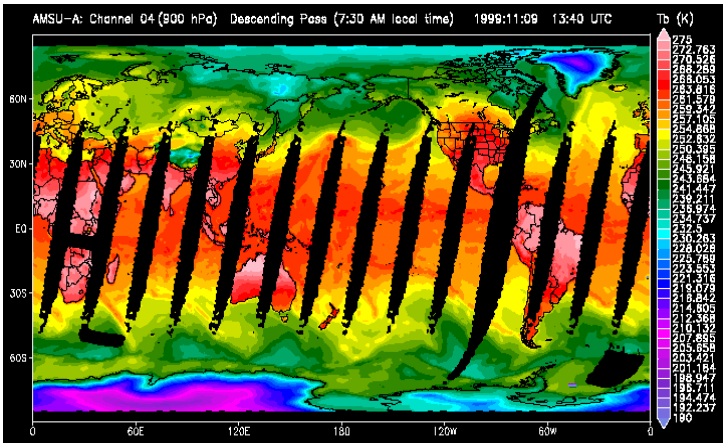
- Species distribution – conservation, evolutionary biology, systematics
- Global processes
- Land and sea "cover" and use
  - Land and environmental management
  - Protected areas
- Disaster management

Image: DFAT Australia

2

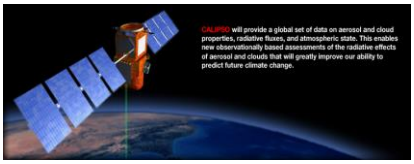
Global Processes and Analyses

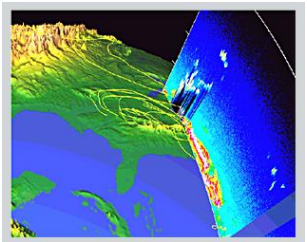


Source: NASAPM-ESIP Center

3

Air Quality





A 3D visualization of data collected by the LITE in September 1994 showing a deep haze layer (yellow and red) over the eastern US and extending into the Atlantic Ocean. Yellow lines trace wind back trajectories, computed from ECMWF data, at the 650 mb level over the 5 days previous to the LITE overpass. The altitude scale is exaggerated. The LITE data extends from sea level to 20 km.

Source: NASA

MAPS

- Measures distribution of CO 3-10km above the earth's surface
- Near global CO database

TOMS

- Measures ozone, UV, aerosols, and volcanic ash emissions

Landsat 7 and Calipso

- Air Pollution Monitoring
  - Ozone, CO, Sulfur Dioxide, Nitrogen Dioxide
- Measure the proportion of light blocked by particulate matter for atmospheric modeling of contaminants

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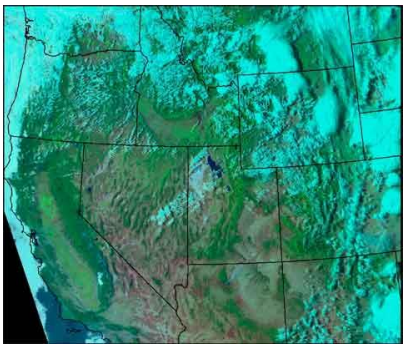
Weather and Climate Data

- Instantaneous data on local, regional conditions
- Longer-term climatological summaries
- Changes in mean, variance



source: U.S. Forest Service

5

Weather Monitoring

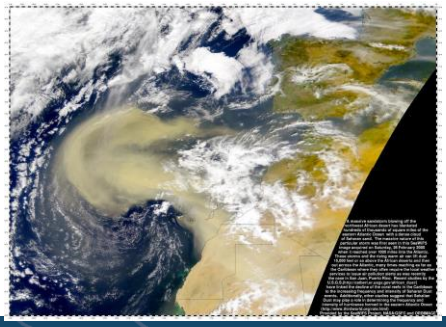
Hurricane Katrina

http://www1.ncdc.noaa.gov/pub/data/images/hurr-katrina-20050828-n18rgb.jpg

https://www.youtube.com/embed/

African Dust storm

Source: http://seawifs.gsfc.nasa.gov/SEAWIFS/IMAGES/Africa/S2000057133341.L1A_HDUN_CAN.SaharanDust Storm.small.jpg



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Aquatic Ecosystems

Source: NOAA

Source: Harri Eliasson

- Runoff
- Flooding
- Water quality
- Water body extent
- River flow rates
- Wetlands mapping
- Water surface elevation and depth
- Ocean color
- Coral reef mapping
- Benthic habitat
- Oil spill monitoring

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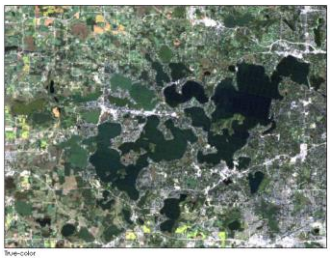
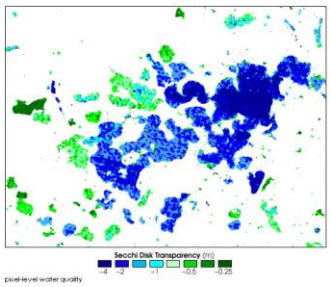
Hydrology



Source: NASA



Source: NASA

Hydrologic Modeling:
- Watershed geometry
- Drainage network
- Empirical Equations
  Annual runoff, Flood peak, Low flow

Runoff Modeling:
- Land use
- Soil moisture
- Topography

Water Quality:
- Suspended sediments
- Estimate chlorophyll
- Temperature
- Turbidity
- Eutrophication

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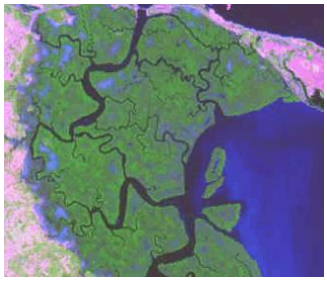
Wetlands



Source: NASA

Understanding of wetland habitat linkages and the complex habitat needs of wetland species

Input on identification, classification and inventory, ecological studies, hydrologic studies, and monitoring change

Source: The Nature Conservancy

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Flooding

- Compare imagery from before a flood event and at different stages as it peaks and recedes.
- Overlaying GIS layers provides information about the areas that have been inundated.
- Map extent of flooded forests

Source: NASA/Goddard Space Flight Center

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Weather after-effects

Hurricane Sandy, Monday October 29

Mantoloking New Jersey

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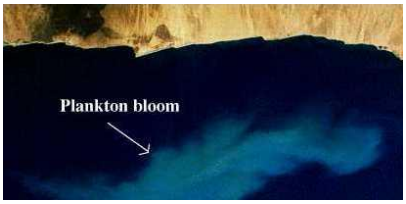
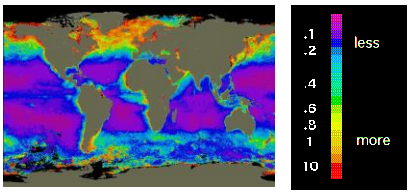
Monitoring Ocean Color



Source: NASA



Source: NASA

- Surges in phytoplankton appear as sudden bright blooms in satellite images
- In contrast, relatively low fluorescence indicates a healthy area and appears darker
- Primary productivity can be measured by determining the amount of light absorbed by phytoplankton chlorophyll
- Sensors detect variations in the intensity of light, called ocean color, at the ocean surface
- Specific bands detect chlorophyll absorption

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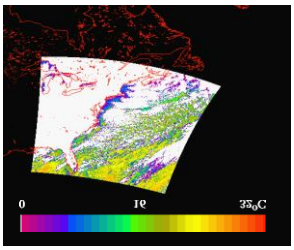
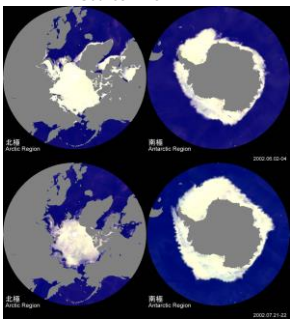
Sea Surface Temperature and Sea Ice



Source: NOAA



Source: NASA

SST

Thermal infrared (TIR) observations

- Measure thermal infrared radiance from sea surface in two different wavelengths
- Calculate "brightness temperatures"
- Convert calibrated radiances to temperatures

Sea Ice

Passive Microwave Sensors

- Salinity
- Surface roughness
- Surface wetness of ice

Uses:

- Locate, monitor, and evaluate sea ice movement

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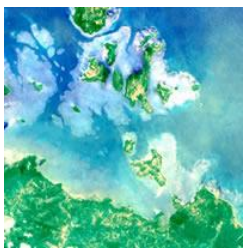
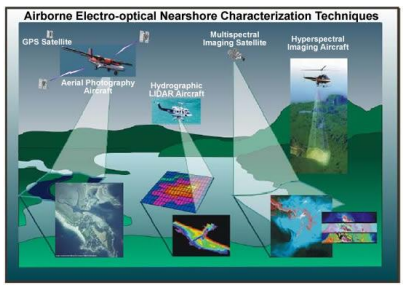
Monitoring Benthic Habitats



Source: NASA, JPL



Source: Science Applications International Corporation

Challenges

- Imagery must penetrate the water and capture the seafloor

Techniques

- High-resolution optical satellite images
- Digital aerial photographs
- Active microwave images
- Optical (video, still cameras, lasers)
- Physical (shipboard acoustic surveys)
- LIDAR

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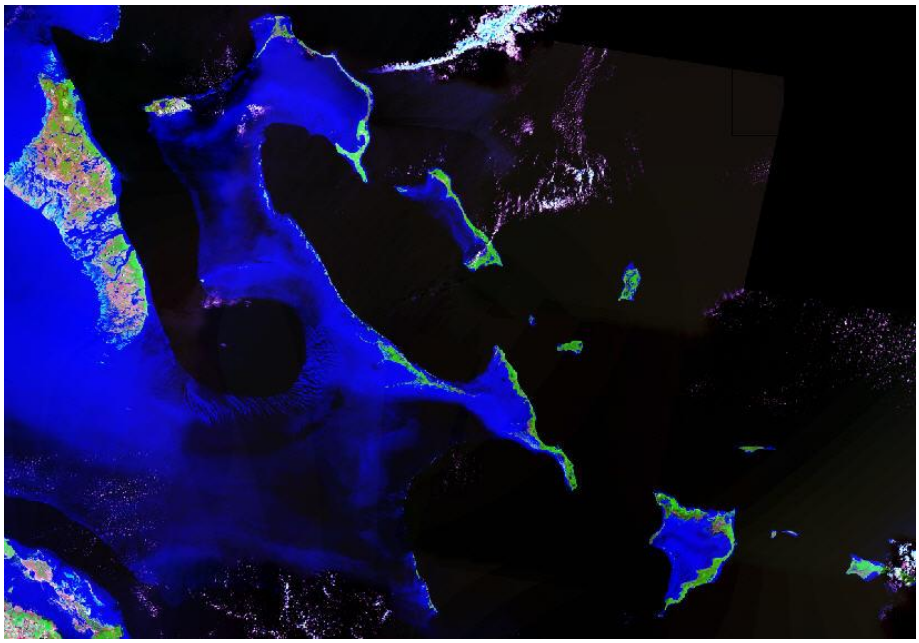
Remote sensing of coral reefs



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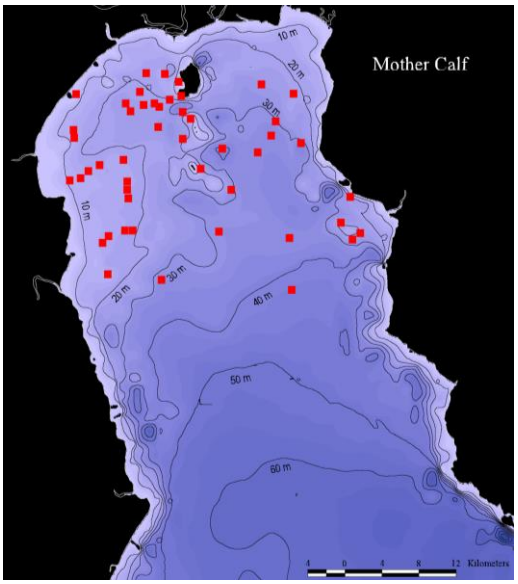
Cetacean habitat use

- Assess habitat use and population distribution.
- For example, Mother/calf significantly distributed within and around 20m isobath.
- Areas where come into contact with human interests.
- Individual positions linked into database.
- Superimpose different data layers (AVHRR, SeaWhiffs & TOPEX).



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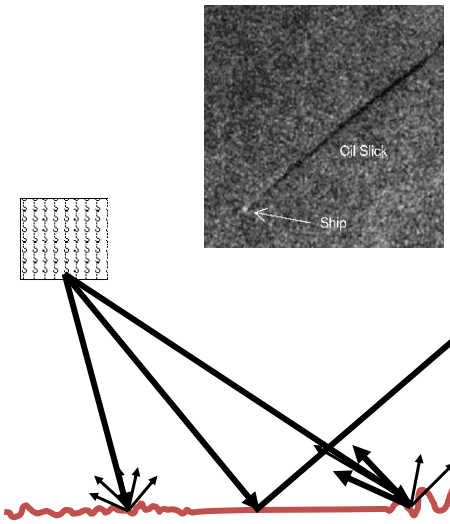
Oil spill detection, mapping and monitoring

© Greenpeace



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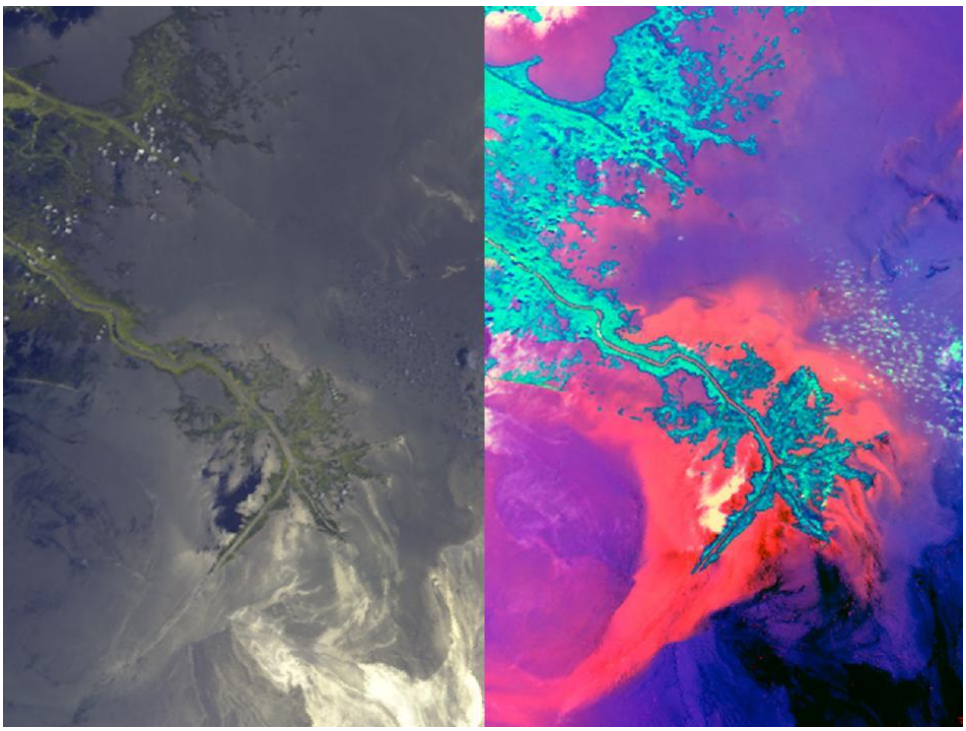

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Fire Mapping and Prediction

Source: U.S. Forest Service

Source: U.S. Forest Service

During Fire Goals:
- Detection
- Behavior
- Monitoring
- Prediction

Post-Fire Goals:
- Assessment
- Burn severity
- Mapping
- Rehabilitation

Fire behavior dependent on:
- Fuel
- Weather
- Topographic Factors

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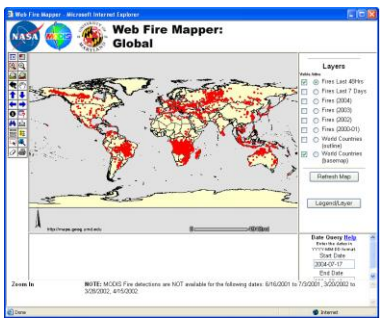
Fire Monitoring

Source: National Weather Service, Sioux Falls



Source: NASA

Frequent wide area coverage of satellite remote sensing provides:
- Location
- Frequency
- Spatial distribution

Fire Phases
- Active
- Smoldering

MODIS
- Detects flaming and smoldering
- Near real-time monitoring capability

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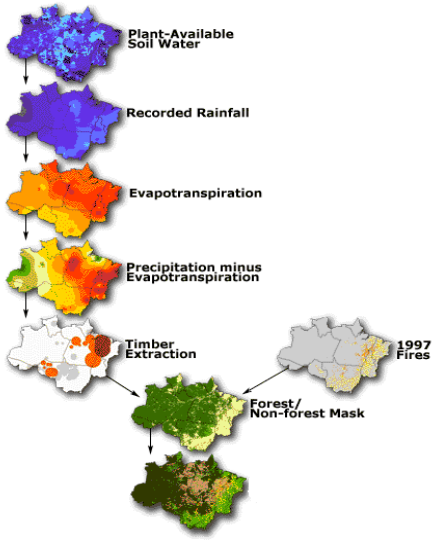
Areas of Fire Risk



Source: http://www.ipam.org.br/fogo/ppt-peten.htm

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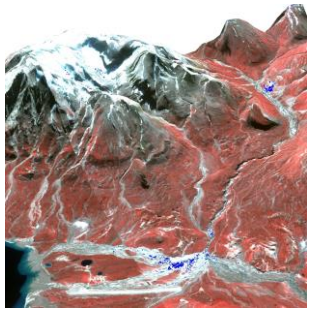
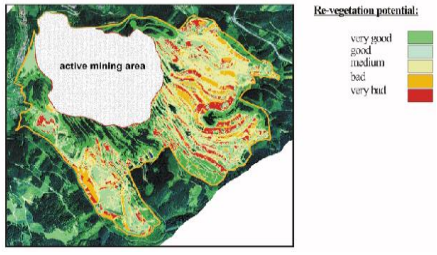
Mining





Source: MINEO project, IST Programme

Hazard monitoring:

Acid generation

Downstream and downwind transport of minerals associated with acid generation

Carbonates and other acid-buffering minerals that neutralize acidic, metal-bearing solutions

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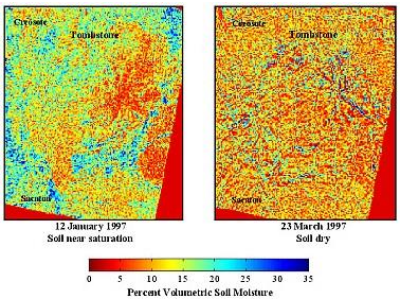
Soil

Source: Dr. Ray Weil, University of Maryland



Source: United States Department of Agriculture-ARS, Southwest Watershed Research Station

Moisture Content
- Detected by Reflectance or Radar Imagery

Texture
- Sharpness of the soil moisture boundaries
  - Sharp = Coarse
  - Gradual = Fine

Chemical Composition
- Alters reflectance

Other indicators of soil characteristics
- Vegetation
- Drainage patterns

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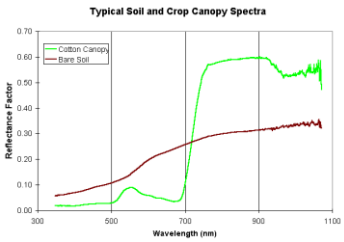
Agriculture

Source: U.S. Department of Agriculture, Agricultural Research Service



Source: U.S. Department of Agriculture, Water Conservation Laboratory

Basis of Remote Sensing Applications:
- Different spectral characteristics of soil and crops
- Density estimates based on the 'red gap'(vegetation indices, Fractional cover, LAI)

Thermal Sensing applications
- Surface temperature detection
- ET estimates
- Crop water stress
- Deficit indices

Other Applications
- Forage estimation for rangelands

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Precision Agriculture

❑Areas of land/crops within a field are managed with different levels of input

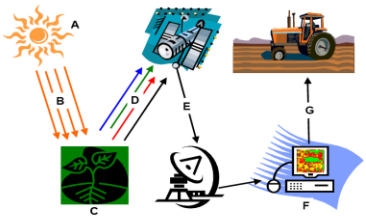

Figure 4. The remote sensing process.

Figure 4 illustrates a satellite remote sensing process as applied to agricultural monitoring processes. The Sun (A) emits electromagnetic energy (B) to plants (C). A portion of the electromagnetic energy is transmitted through the leaves. The sensor on the satellite detects the reflected energy (D). The data is then transmitted to the ground station (E). The data is analyzed (F) and displayed on field maps (G).

Source: U.S. Department of Agriculture, Agricultural Research Service

Integrates remote sensing, GPS, GIS:

- Yield monitoring and ground sampling identifying plant growth and yield variability

Airborne multispectral and hyperspectral digital imaging system:

- Identification of optimal wavelengths and band combinations
- Detect water stress, nutrient deficiencies, and pest infestations for cotton, grain, and other crops

Variable Rate Technology

- Maximize efficiency of water and nutrients

Benefits:

- Reduce cost of crop production
- Reduce risk of environmental pollution from agrochemicals applied at levels greater than those required by the crop can be reduced (Earl et al., 1996)

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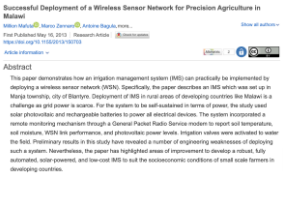

Successful Deployment of a Wireless Sensor Network for Precision Agriculture in Malawi

Abstract

This paper demonstrates how an irrigation management system (IMS) can practically be implemented by deploying a wireless sensor network (WSN). Specifically, the paper describes an IMS which was set up in Manja township, city of Blantyre. Deployment of IMS in rural areas of developing countries like Malawi is a challenge as grid power is scarce. For the system to be self-sustained in terms of power, the study used solar photovoltaic and rechargeable batteries to power all electrical devices. The system incorporated a remote monitoring mechanism through a General Packet Radio Service modem to report soil temperature, soil moisture, WSN link performance, and photovoltaic power levels. Irrigation valves were activated to water the field. Preliminary results in this study have revealed a number of engineering weaknesses of deploying such a system. Nevertheless, the paper has highlighted areas of improvement to develop a robust, fully automated, solar-powered, and low-cost IMS to suit the socioeconomic conditions of small scale farmers in developing countries.

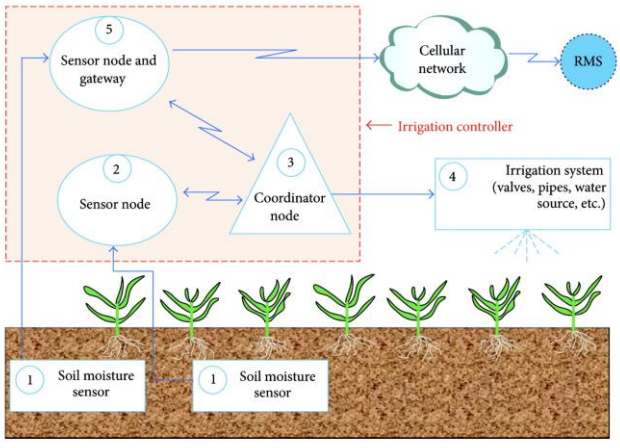

Figure 2 The architecture of the irrigation station.

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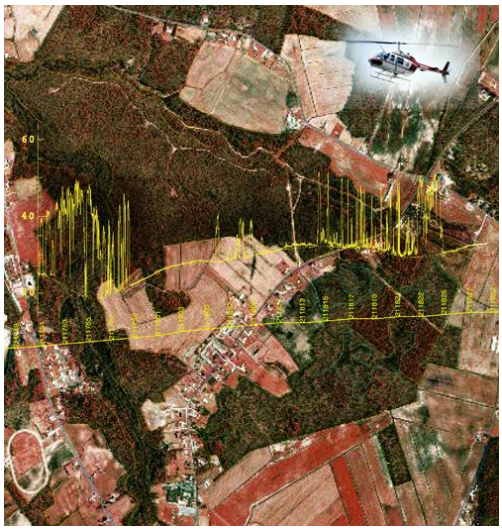
Forestry



Source: Ross Nelson, NASA Goddard Space flight Center

Tree height
Volume
Stand density
Biomass
Leaf area index
Structure
Forest Health

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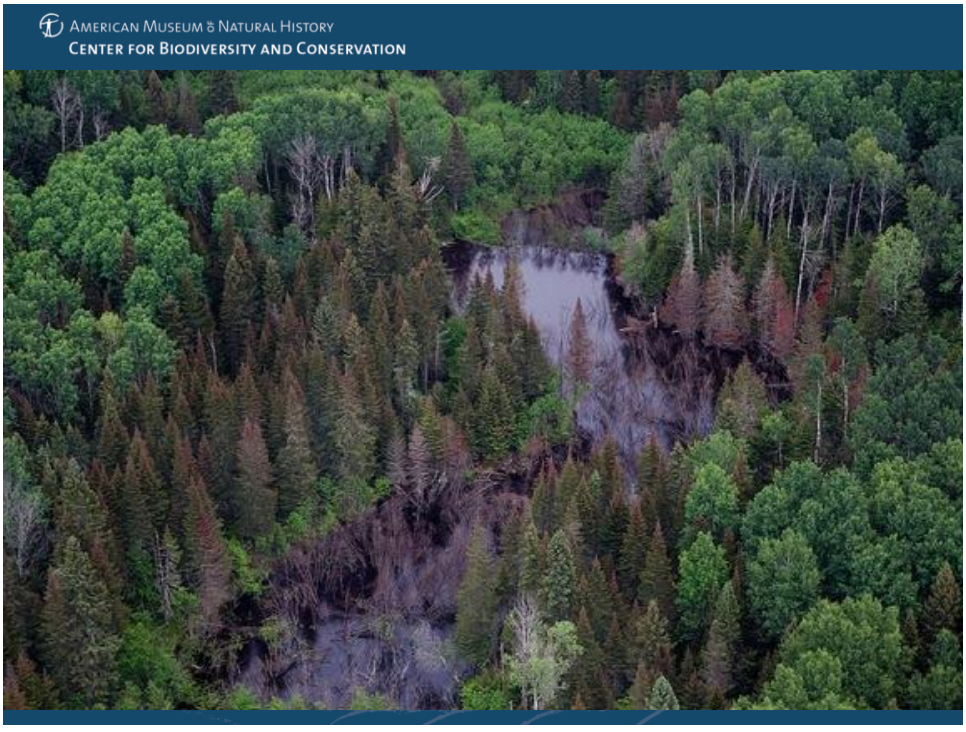

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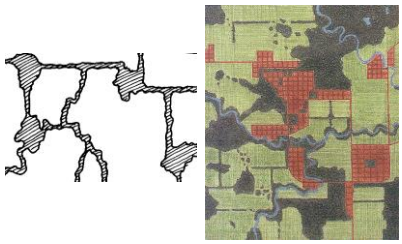
Landscapes



Source: University of Idaho

Land Use Land Cover Change (LULCC)

- Repeated inventories of land use and land cover from space
- Simulation of processes (land conversion and use) taking place on the ground

Landscape ecology

- Spatial patterns of landscapes can be observed and documented to model landscape metrics and indicators.

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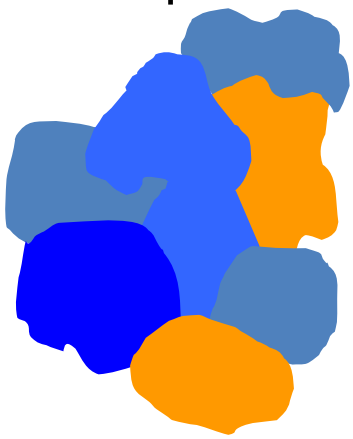
Patches and Landscapes

Patch: land cover is continuous, invariant



Landscape: mosaic of patches of two or more land-cover types

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As Resolution Increases, Landscapes Appear More "Patchy"

Level I: 15 broad ecological regions

Level II: 52 ecological regions

source: U.S. Environmental Protection Agency

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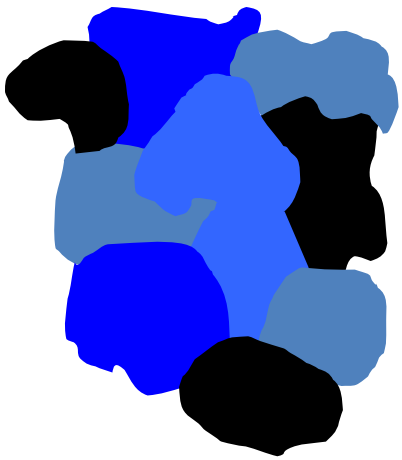
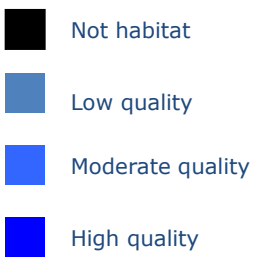
Variation in Habitat Quality





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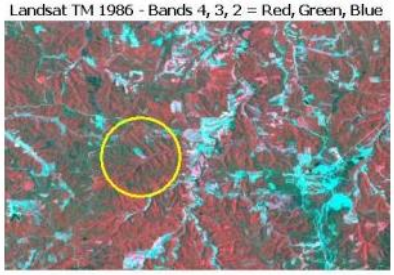
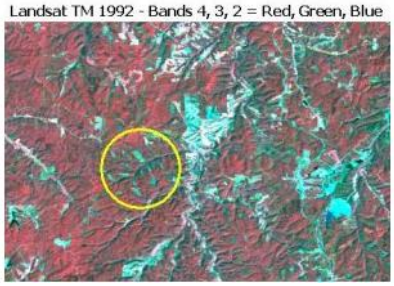
Landsat TM 1986 - Bands 4, 3, 2 = Red, Green, Blue



Landsat TM 1992 - Bands 4, 3, 2 = Red, Green, Blue



Source: Columbia Environmental Research Center, United States Geological Survey

Deforestation

Consequences:

- Loss of the land's protective and regenerative properties
- Local, regional, and global repercussions

❑**Management Priorities:**

- Assess regional land cover change
  - Monitor:
    - Physical structure
    - Vegetation and Species Richness
    - Patterns and rates of Change

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Quick examples

- Climate change vulnerability
- IUCN Red List threat categories
- Connectivity modeling

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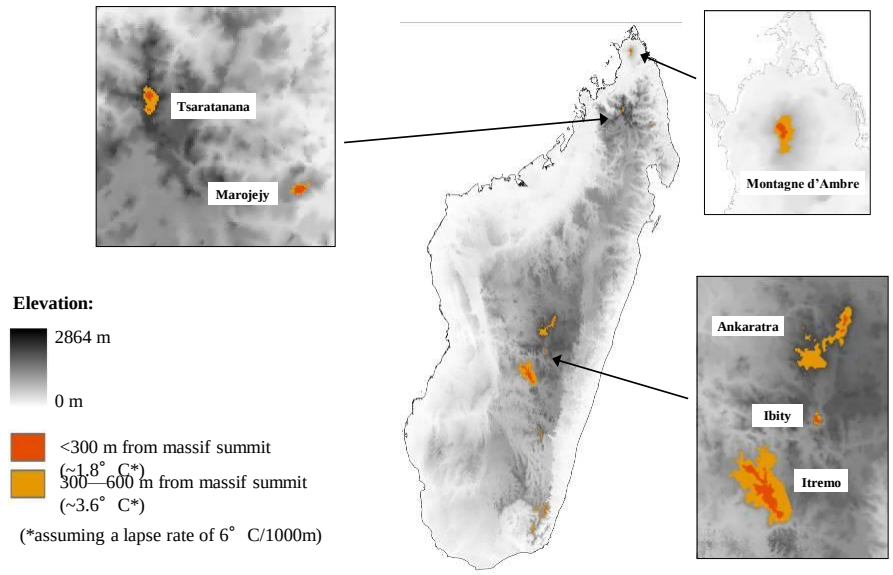
Identifying areas of extinction vulnerability to climate change



(Raxworthy et al. 2008 *Global Change Biology*)

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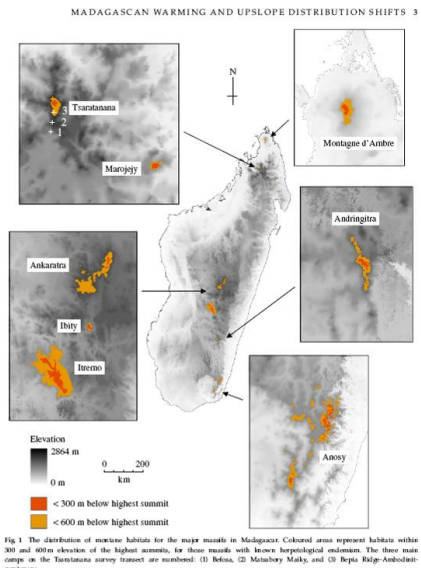

Fig. 1 The distribution of montane habitats for the major massifs in Madagascar. Coloured areas represent habitats within 300 and 600 m elevation of the highest summits, for those massifs with known herpetological endemism. The three main camps on the Tsaratanana survey transect are numbered: (1) Befosa, (2) Matsabory Maiky, and (3) Bepta Ridge-Ambodinisaratanana.

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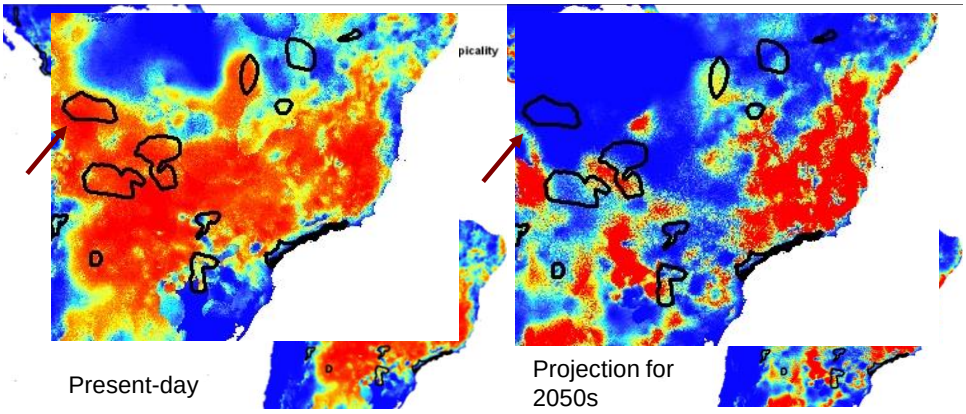
Loss of suitable climate space under future climate change for the jaguar



Blair et al. *Frontiers of Biogeography* 2012

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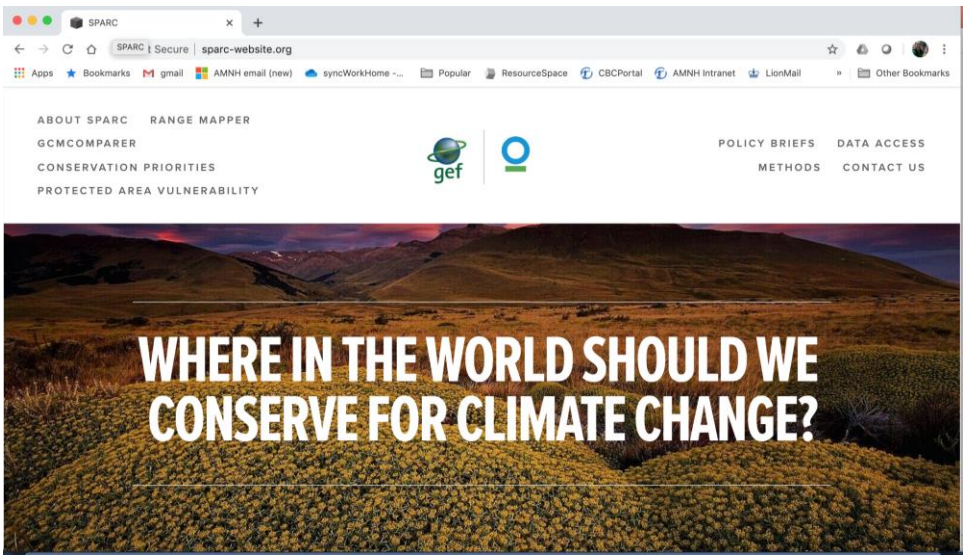

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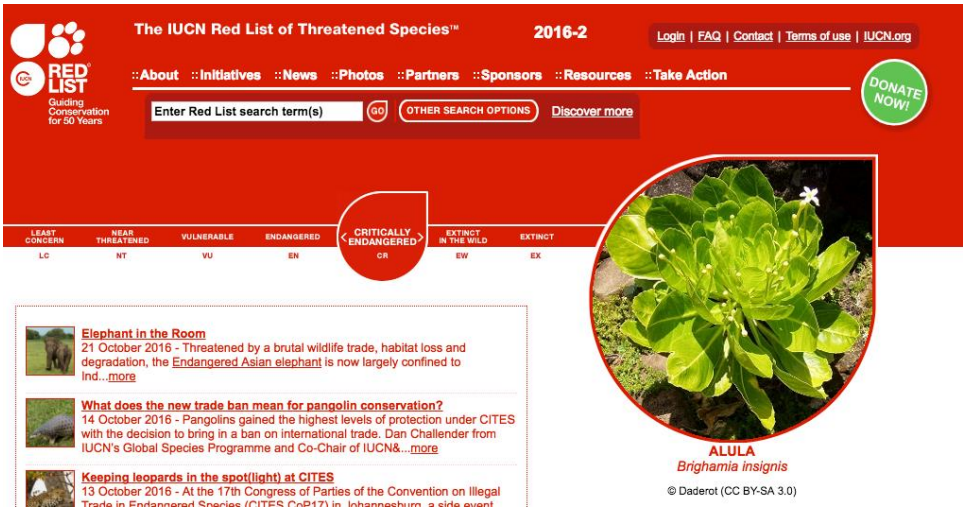
Informing priorities



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IUCN greatly underestimates threat levels of endemic birds in the Western Ghats

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ABSTRACT

The validity of the threat status assigned to a species by the International Union for Conservation of Nature's (IUCN) Red List relies heavily on the accuracy of the geographic range size estimate for that species. Range maps used to assess threat status often contain large areas of unsuitable habitat, thereby overestimating range and underestimating threat. In this study, we assessed 18 endemic birds of the Western Ghats to test the accuracy of the geographic range sizes used by the IUCN for their threat assessment. Using independently reviewed data from the world's largest citizen science database (eBird) within a species distribution modeling framework, our results show that: (a) geographic ranges have been vastly overestimated by IUCN for 17 of the 18 endemic bird species; (b) range maps used by IUCN contain large areas of unsuitable habitat, and (c) ranges estimated in this study suggest provisional uplisting of IUCN threat status for at least 10 of the 18 species based on area metrics used by the IUCN for threat assessment. Since global range size is an important parameter for assigning IUCN threat status, citizen science datasets, high resolution and freely available geo-referenced ecological data, and the latest species distribution modeling techniques should be used to estimate and track changes in range extent whenever possible. The methods used here to significantly revise range estimates have important conservation management implications not only for endemic birds in the Western Ghats, but for vertebrate and invertebrate taxa worldwide.

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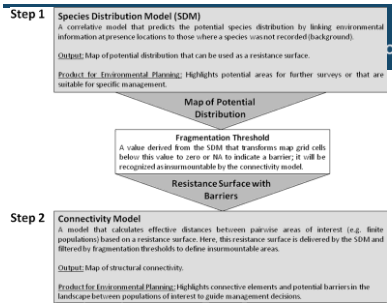

Connectivity Modeling

Table 1 Details of the spectral bands covered by landsat and indices calculated based upon them

Band	Wavelengths (nm)	Ecological meaning and application	Date of scene		
			Aug 4th 2009	Jun 4th 2010	Oct 10th 2010
1—Blue	450–520	Characterization of vegetation types and water	x	x	x
2—Green	530–610	Reflectance of photosynthetic active vegetation			
3—Red	630–690	Characterization of plant species and soil types			
4—NIR	700–1300	Suitable for determining vegetation age and health	x	x	x
5—MIR-1	1570–1780	Detection of snow, clouds, bare ground and vegetation under water stress	x	x	x
7—MIR-2	2100–2350	Characterization of geology and water bodies	x	x	x
6—TIR	10,400–12,500	Temperature measurements	x	x	x
Index	Calculation				
NDVI	(NIR-red)/(NIR + red)	Landuse and vegetation density	x	x	x
Greenness Brightness Wetness	Tasseled cap transformation, involving bands 1–5 & 7	Comparable to a principal component analysis to transform correlated bands into orthogonal axes			

Variables finally included into the SDM after accounting for multi-collinearity are marked with an x

NIR near infrared, *MIR* middle infrared, *TIR* thermal infrared, *NDVI* Normalized Difference Vegetation Index

Rodder et al. 2016;
Environmental Mgmt

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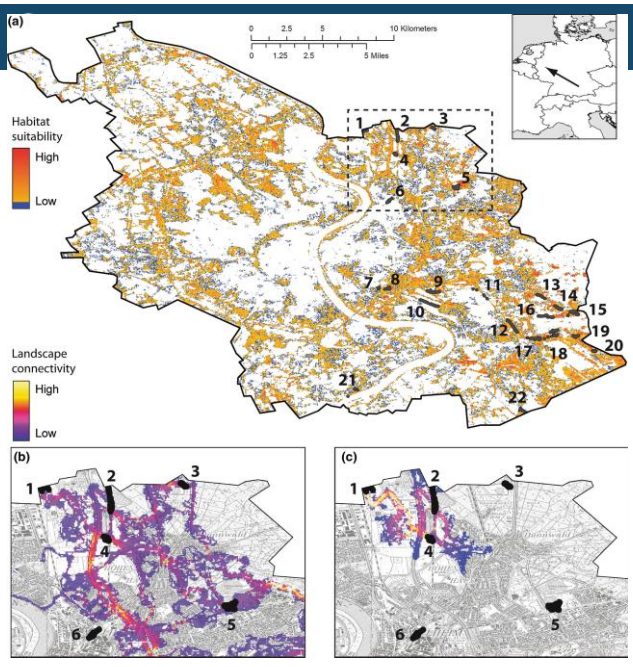

Rodder et al. 2016;
Environmental Mgmt

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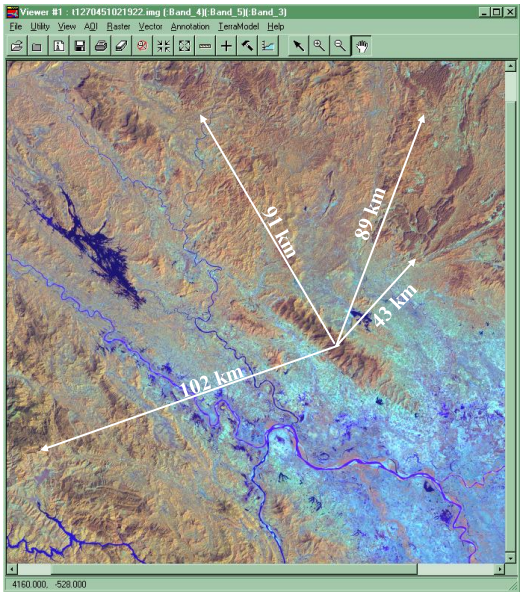
Forest Islands



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Landscape Metrics for Forest Fragmentation

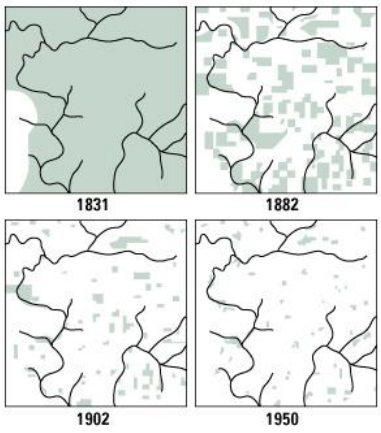
Forest fragmentation has serious impact on habitat viability.

Analysis of patches can help with assessment of that impact.

Fragmentation causes:

Reduce area

Increased edge – what happens at edges?



Fragmentation of a Wisconsin Forest

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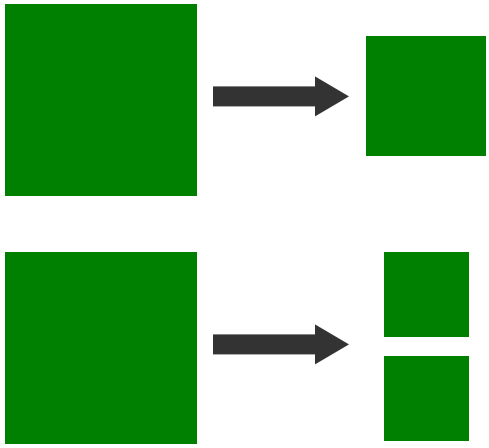
Fragmentation



loss of habitat

loss and breaking apart of habitat

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Edges

Sun

Wind

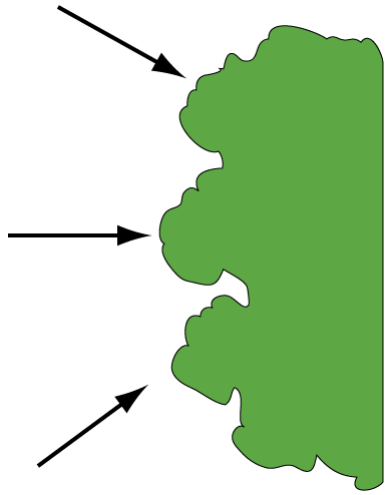
Windborne Pathogens

Invasives

Predation

Shelter for grazers

Human Encroachment



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Edge Effects

Suburban and exurban growth can create edges between forest and open grassland or the built environment. Microclimate often changes along an edge-to-interior gradient.

source: National Aeronautics and Space Administration

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Patch characteristics

- **Area** - the size of the patch. Area may be subdivided into edge versus interior (core) area, with edges defined by buffering
- **Perimeter (Edge)** - circumference of a patch.
- **Shape complexity** - often summarized in terms of normalized edge/area ratio

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Patch Area

- Most fundamental metric. Ecologically relevant.
- May affect:
  - Species diversity
  - Population viability in certain species
  - Density of populations
- Easy to calculate (raster or vector)
- Patch area is usually measured as the amount of uninterrupted habitat of interest that is bounded on all sides by differing habitat.

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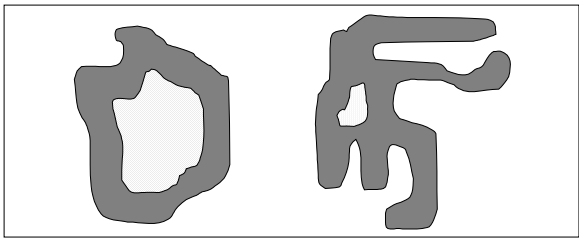
Shape Metrics

• Shape of a patch of habitat relates to edge and colonization probability

• Where two remnants are of an identical size, the remnant with less convoluted shape will contain a greater core area

• More convoluted patches will be more 'spread out' and therefore accept more dispersing animals and plants

• Thus core area may be seen as an interaction between area and shape.



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Range of Shape Metrics

- Shape index = the perimeter of the patch (m) divided by the square root of the patch area (ha) and adjusted for circular standard.
  - SI = edge length/(2√π*area)
  - How "round" it is
- Perimeter/area ratio = perimeter(m)/area(ha),
- Fractal dimension is a measure of shape complexity. Fractal Dimension = 2ln p/ln a.
- Patch elongation may be described by length and width ratio. Length and width are the dimensions of the narrowest rectangle that encloses a patch.

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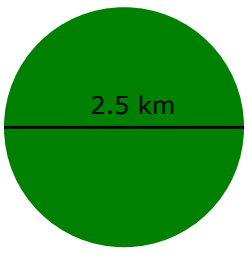
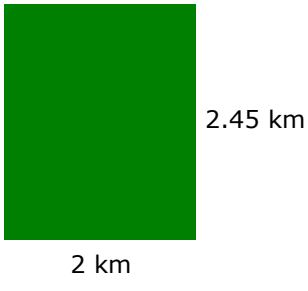
Edge to Interior Ratios



edge: 7.85 km
interior: 4.9 km^2
ratio: 1.6:1



edge: 8.9 km
interior: 4.9 km^2
ratio: 1.8:1

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Advantages of RS and GIS

- Cost-effective method of monitoring land cover and use
- Allow monitoring of global processes
- Can observe remote areas
- Enable the integration of many different types of data
- Encourage better information management
- Facilitate historical comparisons
- Create a clear and striking visual product
- Develop and compare options for future land use

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Limitations of RS and GIS

- Cost of satellite images, software and equipment
- Cloud cover
- Error in data interpretation
- Satellite coverage
- Lack of visible light
- Large data storage needs
- Limited historical data
- Lack of good species data

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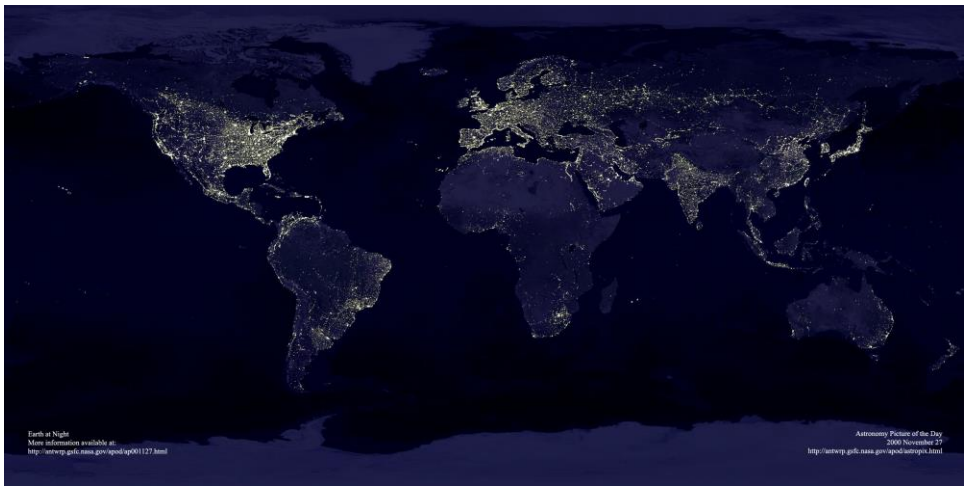
Population distributions



Nighttime lights - November 27, 2000

http://antwrp.gsfc.nasa.gov/apod/image/0011/earthlights2_dmsp_big.jpg

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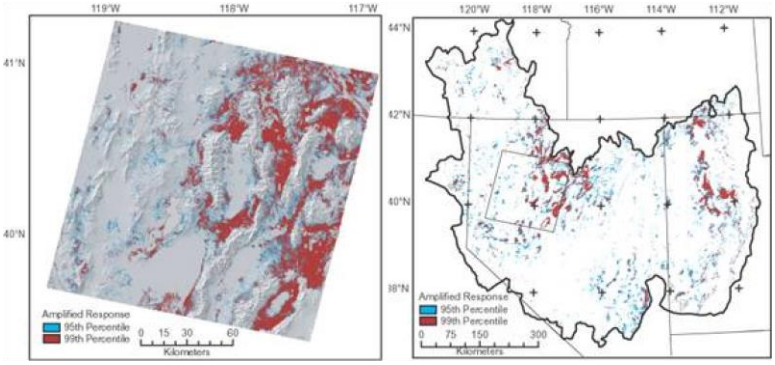
Remote Sensing and Management of Invasive Species



Local and regional distribution of cheatgrass based on species' phenological response to precipitation.
Helps with where to focus eradication or control efforts.

images courtesy of Bethany Bradley

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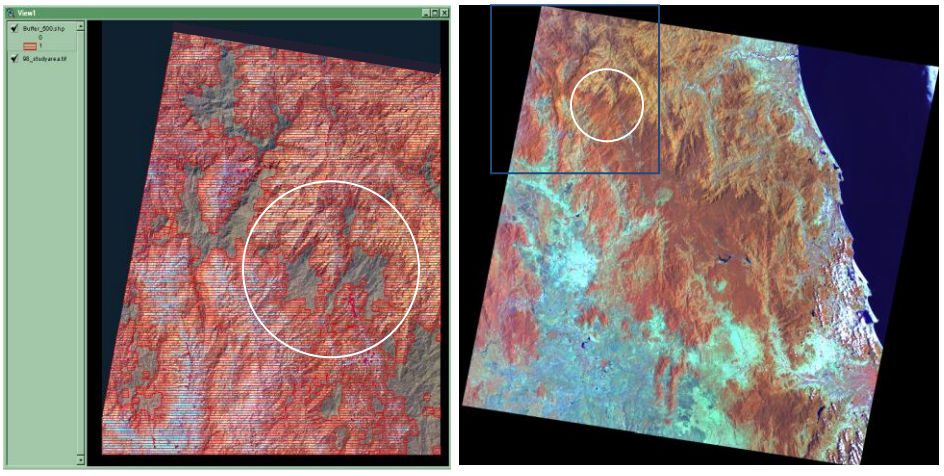
Core Regions and Corridors



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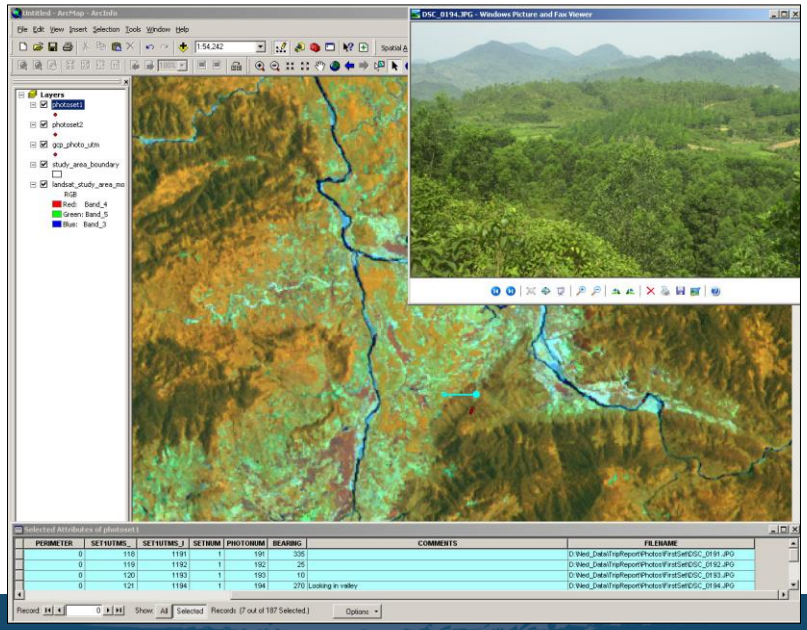
GPS Photo Points



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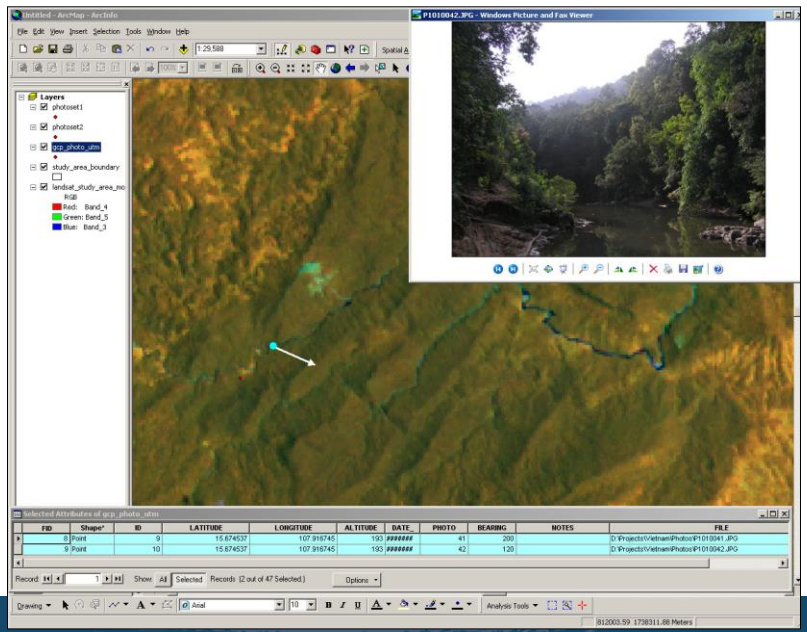
GPS Photo Points



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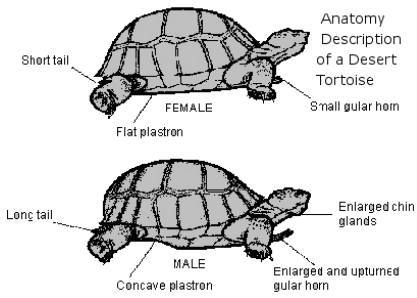
Habitat determination



Source: The Desert Tortoise Preserve Committee

How to model?

The Desert Tortoise

Gopherus agassizi

Threatened – listed under ESA

- Habitat type
- Distribution/Range
- Impact of Human Populations

Planning Goals

- Protection of Tortoise Populations
- Land Management Strategies

Tools

- Habitat Modeling using Empirical Data
  - Benefits of Modeling

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Modeling Habitat

A criteria-based empirical model for determining habitat and need for protection

Source: Kerrie Bathel, SFSU

Habitat Criteria:

- Elevation
- Vegetation Classes
- Soil Classes

Area Requirement:

- Eliminate parcels < 5 ha

Model layers:

1) Elevation derived from DEM
   - Limit dispersal of species to a narrow gradient between 300m - 1067m.
2) Vegetation maps from satellite image classifications
3) Conducive surfaces and topsoils for burrowing identified from remotely sensed soil and geological maps

Additional Criteria?

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