Spatial and temporal variability in habitat use:
Badgers (*Meles meles* and *Taxidea taxus*) in Mediterranean ecosystems

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INTRODUCTION

Determining and predicting species habitat use is complicated by the inherent spatial and temporal variability of resource availability. This is particularly problematic as land cover and its phenology are predicted to change under future climate conditions. Species may be responding to habitat patchiness, phenology or both. Further, species life-cycles may be synchronized to respond to habitat cues. Here we propose that (1) remote sensing can provide state-of-the-art habitat descriptors at multiple spatial and temporal scales, (2) animal radio-tracking data can be linked to remote sensing products, and this fusion allows further understanding of species-habitat relationships, and their dynamics, and (3) make informed predictions on whether climate changes would strengthen or decouple these relationships.

Question(s):

Do species respond to spatio-temporal dynamics of their habitat?
If so, are species life-cycles' synchronized with habitat phenology?

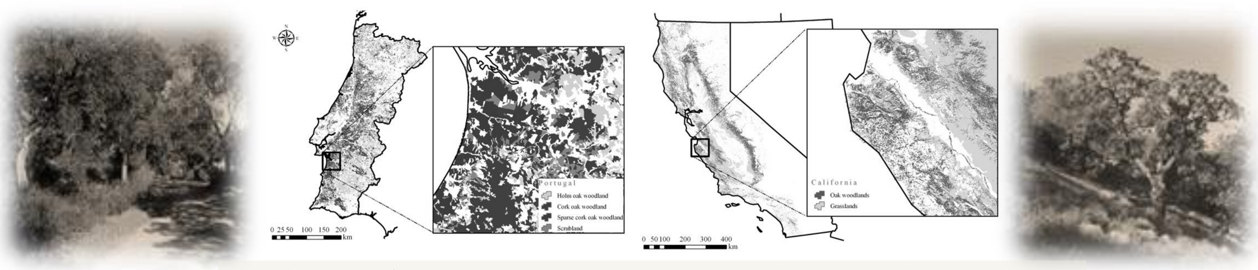

Figure 1 Study areas in Portugal and California

Mediterranean ecosystems

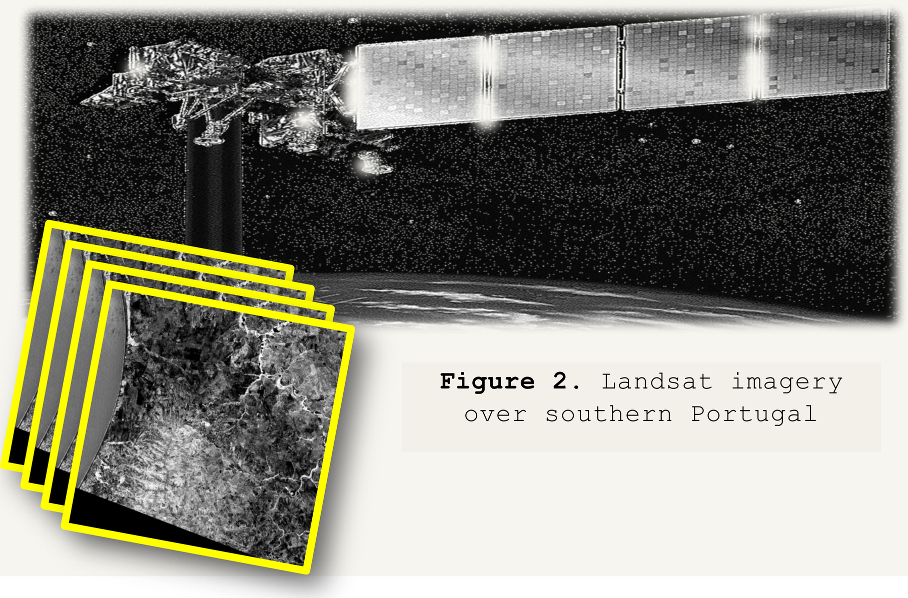

Figure 2. Landsat imagery over southern Portugal

Spatio-temporal matching of remote sensing and radio-tracking data

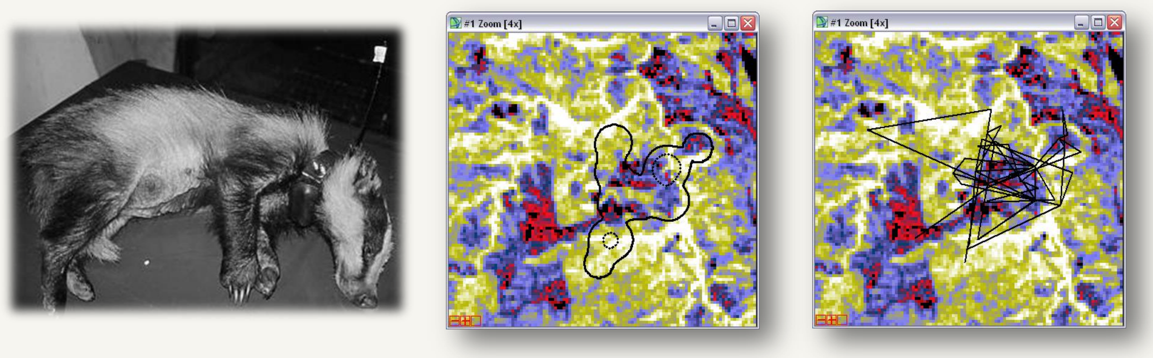

Figure 3. European badger radio-tracking: home-range (top) and movements (bottom) overlaid on top of NDVI map (red is low NDVI and green is high NDVI)

METHOLDS + RESULTS

European badger (*Meles meles*)

Figure 4. European badger and its yearly life cycle

- General **distribution** in Europe
- **Social**
- Construct **sets**
- Inhabits **many ecosystem types**
- In Mediterranean ecosystems tracks spatial and temporal variability of food resources
- **Life-cycle:** delayed implantation, birth in late winter, weaning in early summer

American badger (*Taxidea taxus*)

- Not widely distributed
- **Social**
- Requires **burrows**
- Inhabits **many ecosystem types**
- Tracks spatial variability of food resources
- Ecology not fully known
- **Life-cycle:** implantation after mating, birth in early spring, weaning in early summer

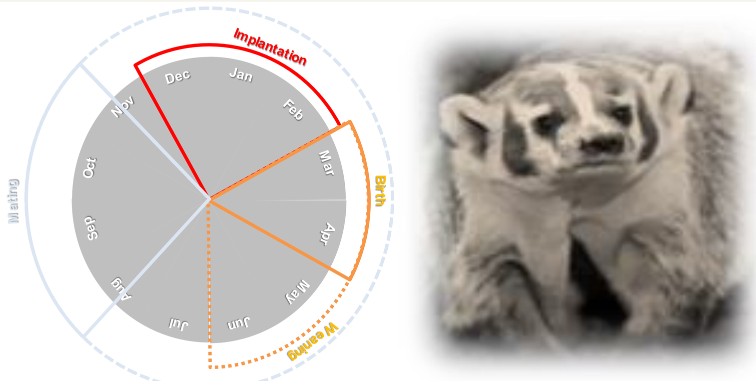

Figure 5. American badger and its yearly life cycle

Test descriptors of ecosystem type and function

- Land cover
  CORINE 2000 (Figure 6a)
- Canopy cover
  PCA of Landsat bands
  (Figure 6b; Carreiras et al. 2006)

$$(TCC = 63.626 - 447.222b5 + 623.837b4 - 714.626b3 + 281.354b7)$$

Productivity

Normalized Difference Vegetation Index (NDVI) $NDVI = \frac{(b4-b3)}{(b4+b3)}$

Green NDVI $NDVI_g = \frac{(b4-b2)}{(b4+b2)}$

Simple Ratio Index (SRI) $SRI = \frac{b4}{b3}$

Atmospherically Resistant Vegetation Index (ARVI) $ARVI = \frac{b4-(2b3-b1)}{b4+(2b3-b1)}$

Soil Adjusted Vegetation Index (SAVI) $SAVI = \frac{(1+L)*(b4-b3)}{(b4+b3+L)}$

Stress

Soil Adjusted Vegetation Index (SAVI) $SAVI = \frac{(1+L)*(b4-b3)}{(b4+b3+L)}$

Structure Insensitive Pigment Index (SIPI) $SIPI = \frac{b4-b1}{b4-b3}$

Plant Senescence Reflectance Index (PSRI) $PSRI = \frac{b3-b1}{b4}$

Moisture Stress Index (MSI) $MSI = \frac{b5}{b4}$

Normalized Difference Water Index (NDWI) $NDWI = \frac{b4-b5}{b4+b5}$

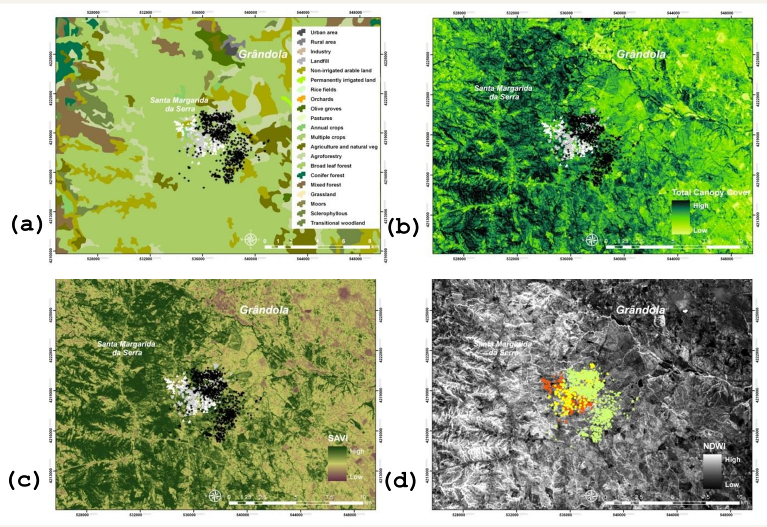

Figure 6. Landsat products used to define: (a) land cover type (CORINE land cover for 2000), (b) Total canopy cover, (c) vegetation productivity (SAVI), and (d) canopy stress (NDWI). Dots represent badger radio-tracking locations.

Analysis:

Response variable: Badger presence

Predictor variable(s): "snap-shot" habitat descriptors for land cover, canopy cover, productivity and stress

Evaluation: Aikake's Information Criteria (AICc) and Area Under the Curve (AUC).

Results:
The best models included land cover type, canopy cover, productivity and stress descriptors.

The best models (in yellow) show that NDVI = SAVI in performance.

Table 1. Nested GLM used to predict European badger presence as a function of habitat descriptors.

Model	Delta AICc	AUC
LC	372.60	0.54
LC + NDVI	251.52	0.61
LC + SAVI	251.42	0.61
LC + NDVI + SIPI	235.63	0.62
LC + NDVI + PSRI	182.69	0.64
LC + NDVI + MSI	202.19	0.63
LC + NDVI + NDWI	219.59	0.63
LC + SAVI + SIPI	235.29	0.63
LC + SAVI + PSRI	182.21	0.64
LC + SAVI + MSI	202.25	0.63
LC + SAVI + NDWI	219.61	0.63
LC + NDVI + SIPI + TCC	33.88	0.69
LC + NDVI + PSRI + TCC	**0.00**	**0.69**
LC + NDVI + MSI + TCC	50.08	0.68
LC + NDVI + NDWI + TCC	40.88	0.68
LC + SAVI + SIPI + TCC	33.88	0.69
LC + SAVI + PSRI + TCC	**0.00**	**0.69**
LC + SAVI + MSI + TCC	50.10	0.68
LC + SAVI + NDWI + TCC	40.88	0.68

Test effect of temporal resolution on habitat descriptors

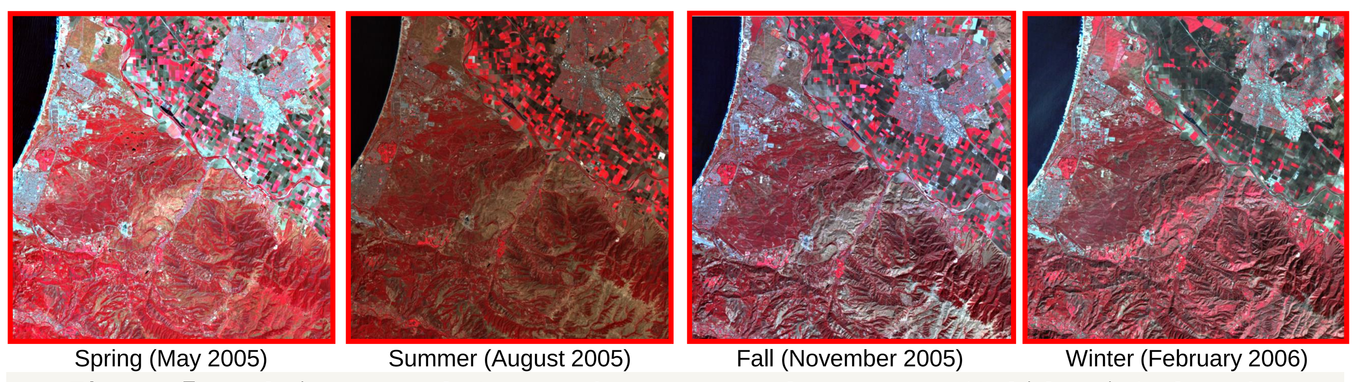

Figure 7. Multi-temporal CIR Landsat scene of Monterey (California) for the tracking period of American badger

Proposed approach
Test for the effects of:
(1) One snap-shot
(2) Seasonal snap-shots
(3) Monthly snap-shots
(Figure 8)

Modelling approach
(1) badger presence
(2) all descriptors of habitat
(3) varied temporal resolution

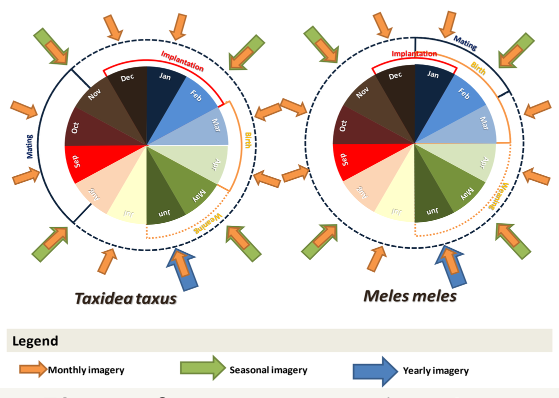

Figure 8. Remote sensing data collection

Table 2. Effect of temporal resolution on badger presence.

Species	Model	ΔAIC	$AICw_i$
Am. badger	Yearly	106.6	0.06
	Seasonal	108.2	0.03
	Monthly	**0**	**0.89**
Eur. badger	Yearly	33.7	0.01
	Seasonal	**0**	**0.98**
	Monthly	32	0.01

Results:
The best models differed by species.

For the American badger the best performing model required monthly resolution.

For the European badger the best model required seasonal resolution.

Test synchronicity between badger life-cycle and ecosystem phenology

Best model
Oak woodlands
Agriculture
Dry agriculture
Canopy cover
Productivity
Stress

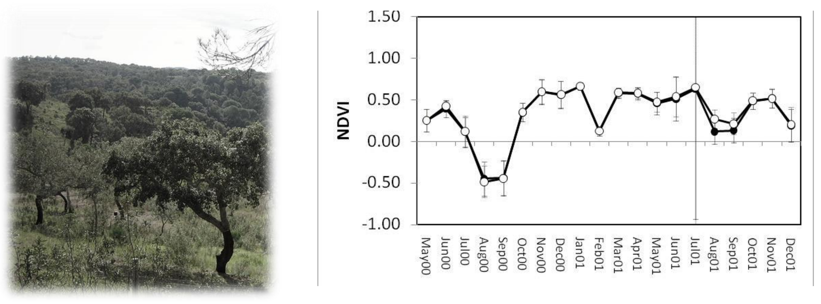

Figure 9. NDVI of oak woodlands. Comparison of productivity at random locations (black circles) with productivity in badger locations (white circles). The high overlap shows a high synchronicity between badger locations and ecosystem productivity.

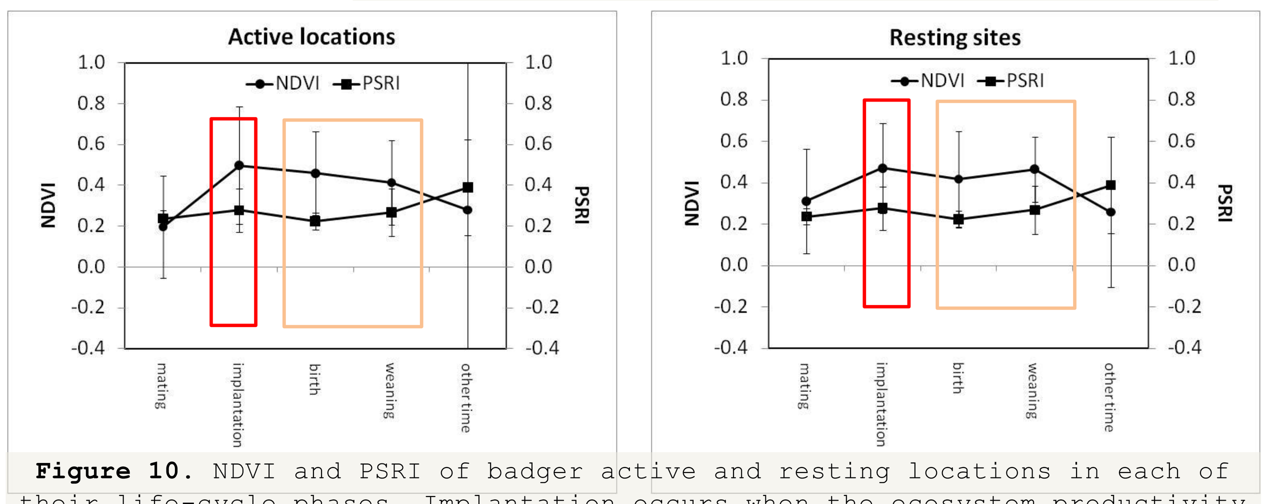

Figure 10. NDVI and PSRI of badger active and resting locations in each of their life-cycle phases. Implantation occurs when the ecosystem productivity increases (NDVI) and stress remains the same (PSRI). All the remaining reproduction-related life cycle phases occur in these highly productive ecosystem phenology phases. High productivity sites were selected both during active and resting bouts.

Results: Oak woodlands are the most important land cover type. Badgers track the productivity of these ecosystems. Reproduction is tied to time periods of high ecosystem productivity.

CONCLUSION

We showed that:

(1) Badger presence was best predicted by habitat descriptors that measured land cover type, cover, productivity and stress. This is likely because the addition of such descriptors can describe flowering and fruiting time, and **enhance the importance of linking ecosystem type and function**

(2) Models were improved with multi-temporal snap-shots of habitat descriptors. In California, it requires monthly descriptors while in Portugal seasonal repetitions are sufficient. **This shows the importance of spatio-temporal matching**

(3) Badgers tracked the productivity of their most preferred habitat over time. This was particularly important over the reproductive season. This suggests a **strong tie between ecosystem productivity and reproduction**

Predicted future change in ecosystem types and functioning can greatly affect badger populations, in particular because of the demonstrated synchronicity between reproduction and ecosystem productivity.

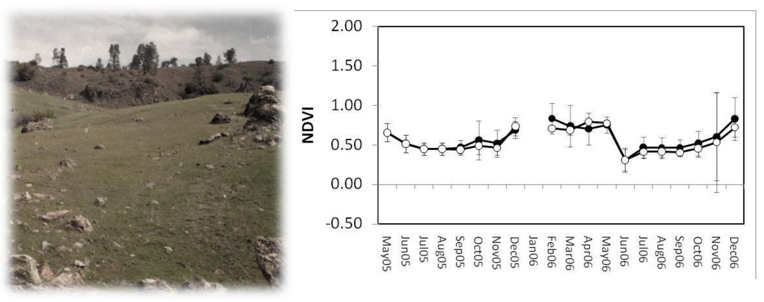

Figure 11. NDVI of Annual grasslands. Comparison of productivity in random locations (black circles) with productivity in badger locations (white circles). The high overlap shows a high synchronicity between badger locations and ecosystem productivity.

Best model
Annual grasslands
Coastal oak woodlands
Coastal sage scrub
Canopy cover
Productivity
Stress

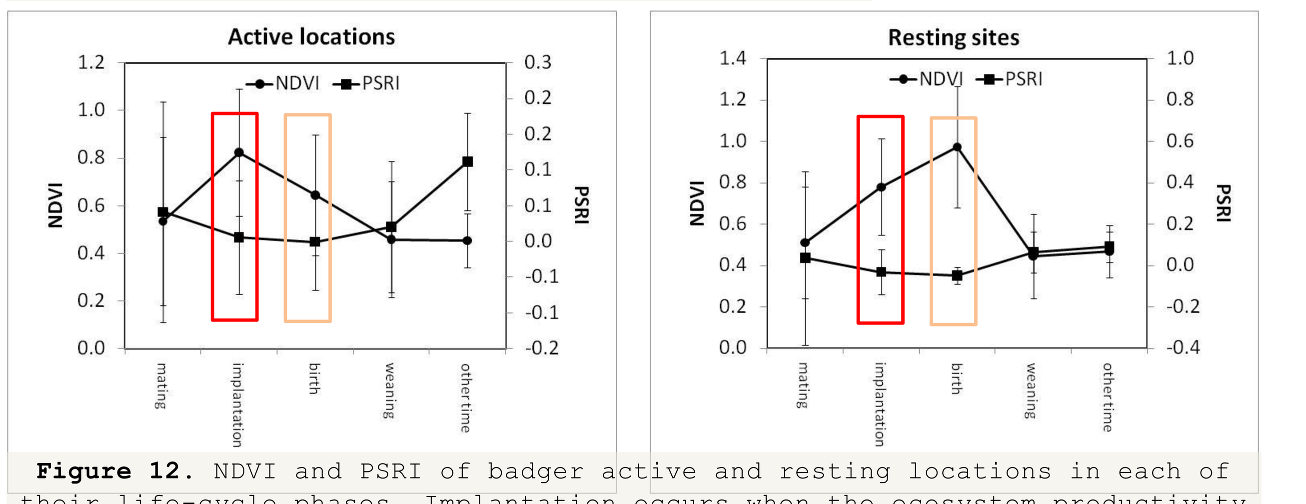

Figure 12. NDVI and PSRI of badger active and resting locations in each of their life-cycle phases. Implantation occurs when the ecosystem productivity dramatically increases and birth also occurs in this highly productive ecosystem phenology phase. High productivity sites were selected both during active and resting bouts.

Results: Annual grasslands are the most important land cover type. Badgers track the productivity of these ecosystems. Implantation and birth are tied to time periods of high ecosystem productivity.