Detection of waterholes by Vegetation Index in the habitat of bighorn sheep (*Ovis Canadensis*) in Baja California

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ABSTRACT

The desert bighorn sheep is adapted to the extreme conditions of arid ecosystems. The amount and distribution of watering holes is an essential component of the habitat of this species. With information provided by people in Sierra Santa Isabel a database of potential sites watering sites was obtained, which was taken as reference of spectral information for water and vegetation. Two images of Landsat 8-OLI were processed; the first corresponded to the end of the drought and the second rainy season of 2013. A false-color composite was made between bands where water has an absorption behavior (band 5 and 7) and a Normalized Difference Vegetation Index

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(NDVI). Field visits to the existence of 15 watering holes of which 11 had evidence of use by the bighorn were confirmed. The abundance of plant species *Tamarix ramosissima*, *Juncus acutus*, *Typha domingensis and Psorathamnus spinosus* contributed substantially NDVI values and facilitated the detection of watering holes.

Subject Conservation Biology, Remote Sensing

Keywords watering hole, bighorn sheep, Landsat, NDVI

INTRODUCTION

The desert bighorn (*Ovis canadensis*) have adapted to extreme of desert conditions in arid areas of southwestern North America. Its efficient mechanisms for obtaining water through oxidative metabolism of food, allow it to remain in deserts where there is no water available (Broyles and Cutler, 1999). According to Lane et al. (1994), from 1901 to 1987, temperature increased at a rate of 0.12 °C per decade and annual average precipitation decreased by 20% in the desert of California. Climate change will further exacerbate dry conditions. The main effects will be a reduction in the availability of forage and standing water (Sandoval et al. 2014).

Despite the importance of locating and monitoring the availability of watering sites in Baja California distribution of this vital habitat resource is unknown. The detection of watering sites is difficult because their inaccessibility in mountain. Mountainous areas in the state of Baja California encompass an area of over 2.000 km^2 with limited road access. Without access roads, it is logistically complicated and expensive to find watering sites (Martinez and Eaton, 2008).

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The use of satellite remote sensing is now widely used for identifying spectral signature of objects from their reflective or absorptive properties in different spectral bands. It is possible to identify vegetation types, soils, and water in inaccessible areas and also obtain a synoptic coverage that allows analysis of vast mountainous regions (Chuvieco, 2010). For our project, multispectral images from the OLI sensor (Operation Land Imager) on the Landsat 8 satellite (Roy et al., 2014) were used to locate watering holes potentially used by bighorn sheep. In arid ecosystems, greater vegetation cover is associated with watering sites. The objective of this study was to locate water holes by analyzing variations in the Normalized Difference Vegetation Index (NDVI) from images of the OLI sensor because the NDVI has a consistent correlation with plant cover and plant biomass productivity (Pettorelli, 2013).

MATERIALS AND METHODS

Study area

The research was conducted in the southernmost area of the Sierra Santa Isabel, located in the central part of the State of Baja California (30° N, 115° W). The mountain range is the largest continuous habitat for bighorn sheep in Baja California (2072 km²) (Fig. 1), with an estimated population of 300–400 sheep (Martinez and Eaton, 2008; Lee et al., 2012). The vegetation is desert scrub, dominated: *Ambrosia dumosa*, *Prosopis microphylla*, *Cercidium microphyllum*, and *Pachycereus discolor* (Gonzalez-Abraham et al., 2010). The climate is warm, with maximum temperatures of 45 °C during the summer. Annual rainfall in southern part of the mountains adjacent to the Gulf of California is less than 50 mm, and 100-150 mm in the central and northern parts of the mountain range (Roberts and Ezcurra, 2012).

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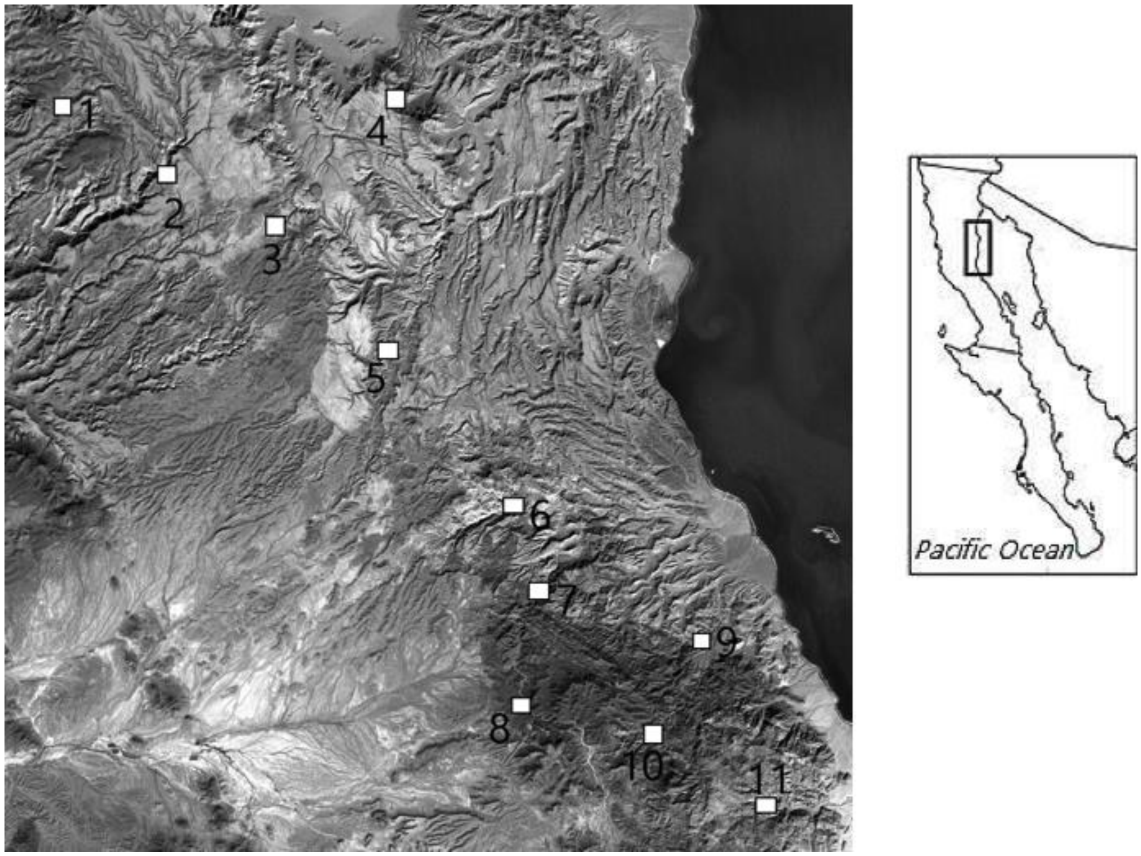

Figure 1. Location of potential sites with watering holes in Sierra Santa Isabel, Baja California (Path 38, Row 39). 1. Matomi, 2. Arroyo Grande, 3. Las Blancas, 4. Canelo, 5. Hemes, 6. Zamora, 7. Cordero, 8. Volcán, 9. Miramar, 10. Azul, 11. Las Palmitas.

Based on information provided by land owners and residents from Sierra Santa Isabel, a database of potential watering sites in riparian areas, natural rock basins, and springs was developed. Spectral information was used to display water and vegetation features. Images taken by the OLI (Path 38 and Row 39), with pixel resolution sensitivity of 30 m, were processed. Images were downloaded from the US Geological Survey website (www.glovis.usgs.gov; data of 12 August and 30 October 2013). The 12 August image represents the end of the dry period, when

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temperatures are highest (40 °C). The 30 October image represents the rainy season with rainfall ranging from 50 to 100 mm (SMN, 2013). The images were co-registered geographically using the ENVI 4.7 program (Exelis, 2012).

Since water holes typically have denser vegetation in arid regions, NDVI was determined for a radius of 1.6 km (1 mile) from the center of the water hole, herds of bighorn usually congregate in this distance from water holes (Smith et al., 1991; Bleich et al., 1997; Gilad et al., 2013).

In arid ecosystems, a positive NDVI >0.30 corresponds to areas with 30% denser vegetation and a negative NDVI corresponds to areas of bare soil surfaces (Purevdorj et al., 1998; Hamlyn and Vaughan, 2010).

In order to know how good is the waterhole is detection using the NDVI, we compared with the normalized difference water index (MNDWI) proposed by Xu (2006), which is based on maximize reflectance of water by using green wavelengths and middle infrared.

Statistical analysis

The data were analyzed using SAS 9.4 software (SAS Institute, 2008) for one-way ANOVA, where locations are independent, and NDVI are Y-dependent variables. Dunnett's multiple comparison tests were used to compare means of location (water hole) with each other and the control. Studentized residuals and predicted values were calculated and normality of the residuals confirmed, using the Shapiro-Wilk test (Zar, 2009). NDVI differences between water holes and control sites were represented with box plots.

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Subsequently, three compounds of bands were used to compare false color detection of water holes: (1) False color infrared (OLI 3, OLI 4, OLI 5), (2) Detection of water holes, using the NDVI (OLI 5, NDVI, OLI 6), (3) Detection rate of water holes, using MNDWI. After confirming the presence of water holes, recording coordinates of the sites, and entering GPS data and we surveyed the sites.

RESULT

We detected 15 water holes, of which 11 were identified as used by bighorn sheep (photographic records). Of these, seven were permanent and four were seasonal (Fig. 1). Those classified as permanent had the highest NDVI scores. The Matomi water hole had an NDVI of 0.48 in the dry season and 0.41 in the rainy season and Arroyo Grande had an NDVI of 0.43 in the dry season and 0.41 in the rainy season.

For permanent water holes, differences between the NDVI in dry and rainy seasons was statistically significant, using Dunnett's test (dry season $p = 0.0161$; rainy season $p = 0.0168$); n > 8). For Matomi, Arroyo Grande, and Palmitas, NDVI was higher in the dry season; for Zamora, Azul, and Miramar, NDVI was higher in the rainy season. At seasonal water holes, there were significant differences, using Dunnett's test (dry season $p = 0.0067$; rainy season $p = 0.0115$, n > 5). At these sites, NDVI was 0.25 in the dry season and 0.29 in the rainy season (Fig. 2).

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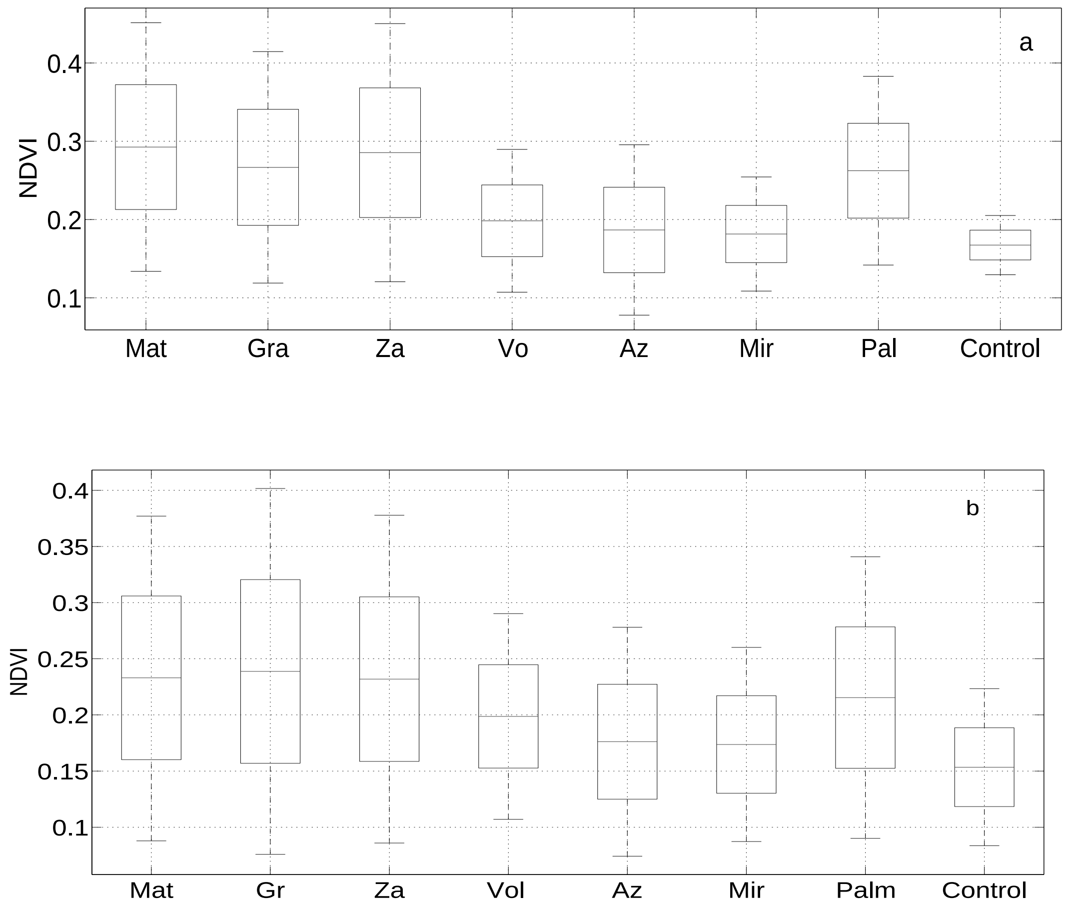

Figure 2. Permanent watering holes in Sierra Santa Isabel. Dry period (A), rainy (B). Nomenclature: Mat= Matomi, Gra= Grande, Za= Zamora, Vol= Volcán, Az= Azul, Mir= Miramar, Pal= Palmito.

ANOVA analysis showed that NDVI of all permanent water holes had a significantly higher NDVI than control sites, during the dry season (dry season F-test = 138.89, p = 0.0001; and rainy season (F-test = 54.06, p = 0.0001) (Figs. 2a and 2b). All seasonal NDVI results were also

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significantly different from the NDVI results of control sites for the dry season (F-test = 690.5, p = 0.0001) and rainy season (F-test = 30.97, p = 0.0001) (Fig. 3).

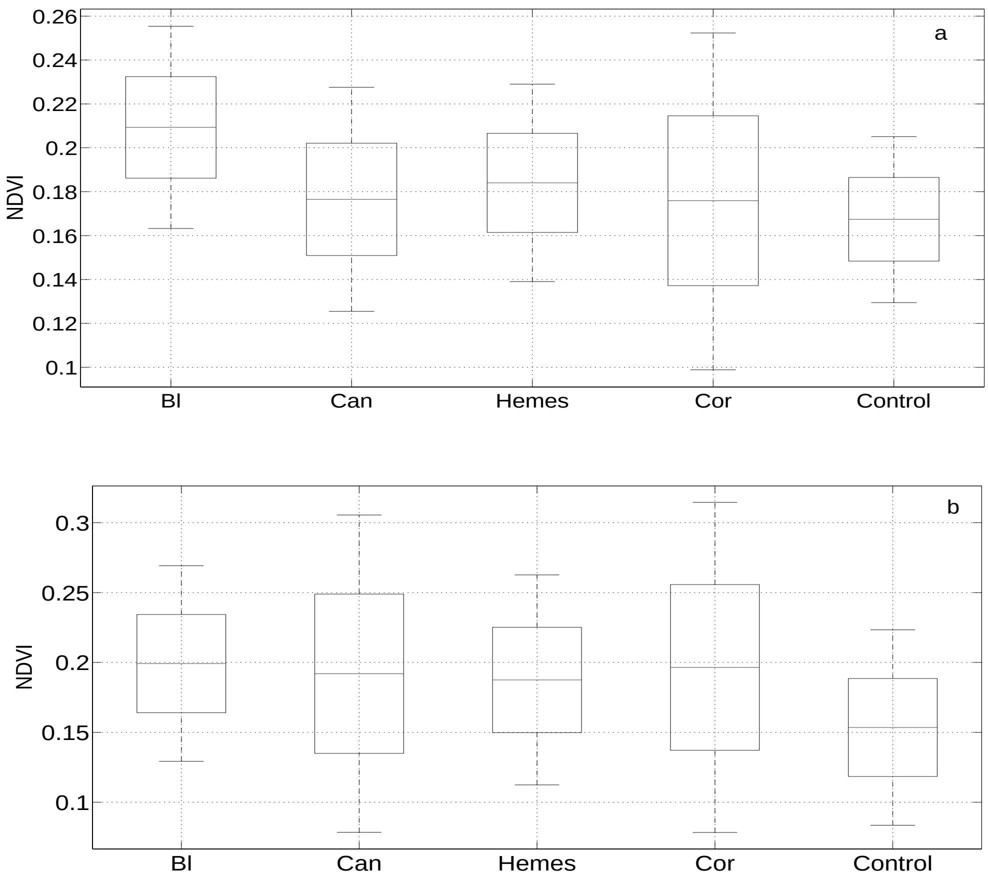

Figure 3. Temporal watering holes in Sierra Santa Isabel. Dry period (A), rainy (B). Nomenclature, Bl = Blancas, Can = Canelo, Cor = lamb.

The false-color composites to detect water holes were OLI 5, NDVI, and OLI 6. The MNDWI was only able to detect a water hole at Zamora. Other water holes were not accurately detected, for example Hemes, Las Blancas, and Zamora, were ambiguous at potential water sites. Four potential water holes, when using NDVI were detected, but their size represents only 15% of the coverage of a pixel (30 × 30 m), as in the case of Hemes (Fig. 4).

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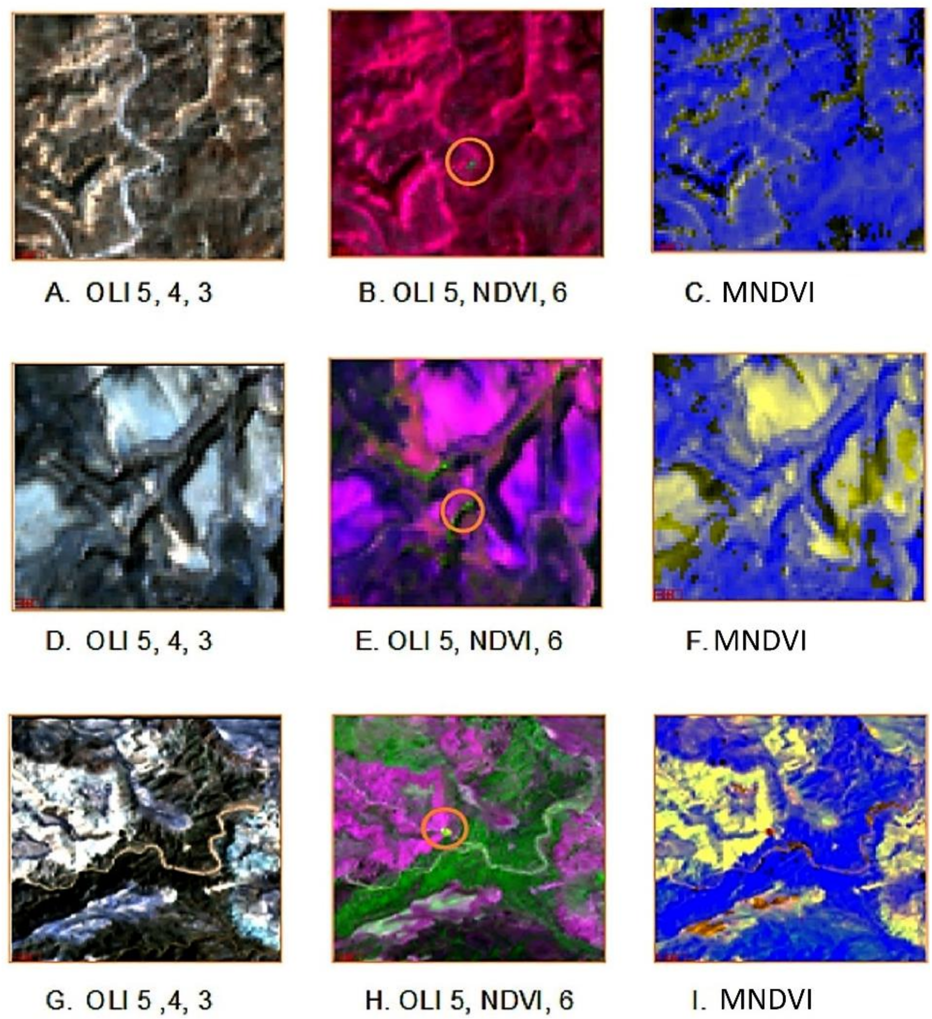

Figure 4. Examples of watering holes detected in Sierra Santa Isabel, Baja California. Hemes, (A) false-color infrared, (B) detection and (C) water hole that is not detected. Las Blancas, (D) false color infrared, (E) detection and (F) water that is not detected. Zamora. (G) false-color infrared, (H) detection and (I) water which was also detected with the MNDWI.

DISCUSSION

The combination of selected spectral bands and NDVI are useful for detecting natural water holes in mountainous arid areas where bighorn sheep live in the State of Baja California in

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Mexico. The spectral signature of vegetation determined by the NDVI was key to the detection of the water holes. The NDVI for these sites and the immediate surrounding area was high, between 0.30 and 0.45, levels in arid areas that contain dense vegetation (Dall'Olmo and Karnieli, 2002; Pettorelli, 2013).

Another detection method for water holes is MNDWI which is effective for detecting water sites, using Band 4 (0.520–0.605 µm) and Band 9 (1.55–1.75 µm) sensors of the Advanced Land Imager satellite (Li et al. (2013). However, MNDWI is designed to measure water content in plant leaves, mainly in farm fields (Ghulam et al. 2008). For our study area, characterized by sparse vegetation of desert scrub, MNDWI generalizes sites with potential water holes. Tucker (1980) suggests that a suitable range for radiometric detection of water holes is 1.55–1.75 nm, which is in Band 6 of the OLI sensor. In combination with infrared and the NDVI, it has greater likelihood for detecting water holes.

In the southern Sierra Santa Isabel area, temporary water holes had the lowest NDVI, similar to the Lower Colorado area, where rainfall is <50 mm/year and is subjected to long droughts (Roberts and Ezcurra, 2012). These water holes are important because they are the only sources of water for much wildlife in this subarea of Sierra Santa Isabel.

The most important contribution to a higher NDVI were abundant plants, typically *Juncus acutus* (rush), *Typha domingensis* (southern cattail), *Psorothamnus spinosus* (smoke tree), *Urtica dioica*

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(stinging nettle), and *Tamarix ramosissima* (saltcedar) that in moist soils adjacent to water sites and are tolerant of saline and alkali conditions (Escobar et al., 2016). Field visits confirmed that at Matomi, Arroyo Grande, and Palmitas, abundant *Brahea armata* (blue palm), endemic to Baja California, contributed substantially to the NDVI.

Final Remarks

The NDVI was key to the detection of watering holes; the index values in these sites were high between 0.26 and 0.45. This method was able to detect watering holes, which facilitated their location in large areas and reduced sampling effort. The amount and distribution of watering holes found in this study confirm the importance of Sierra Santa Isabel for the conservation of bighorn sheep in Baja California, previously mentioned by DeForge et al. (1993). It is recommended that future population monitoring and conservation management and use of bighorn sheep, consider the distribution of these watering holes, which are a vital component of the habitat of this specie.

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