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# Clast mobility within boulder beaches over two winters in Galicia, northwestern Spain

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ABSTRACT

A micro-drone was used to make low altitude flights over boulder beaches at Laxe Brava and Oia in Galicia, northwestern Spain. Flights were made in July 2012, May 2013, and spring 2014. High resolution digital terrain models and orthophotographs, combined with GIS mapping, were used to monitor changes in the position of thousands of boulders. Maximum storm wave height was higher in the winter of 2013–2014 than in winter 2012–2013, and this was reflected in an increase in the proportion of the boulders that moved in the two winters, from 17% to almost 48% at Laxe Brava, and from 53% to almost 88% at Oia. The greater mobility of the boulders at Oia can be attributed in part to their generally smaller size, although there was considerable overlap between the size of boulders that moved and those that did not move within and between the two beaches. There were mobile boulders in areas up to several metres above the high tidal level on both beaches, and boulder transport in the shore-normal and alongshore directions triggered some changes in the beach profiles, particularly in the middle to upper parts of the beaches. Estimates of threshold transport conditions, scaled to boulder mass, breaker height, and other variables, suggested that all but the very largest boulders on the two beaches should have been mobile, even during the summer months when the waves were much lower than in winter. Model over-prediction can be attributed to a number of factors, including: constraints on movement imposed by surrounding boulders; differences in boulder size and their effect on pivoting angles and on the degree to which boulders are exposed or sheltered from wave impact; and difficulties in assigning appropriate values to model coefficients.


## 1. Introduction

Until fairly recently there had been little interest in rocky coasts littered, or occasionally covered, by large boulders, and consequently in rock coasts as sedimentary environments (Felton, 2002; Noormets et al., 2004). Rock coast researchers have traditionally targeted bare shore platforms and cliffs while other coastal researchers have concentrated on sand and gravel beaches, dunes, and other deposits that respond much more rapidly than boulders to changes in waves and other prevailing conditions. The lack of interest in coastal boulders can be attributed in part to the assumptions that: (i) boulders have little effect on the development of rock coasts and (ii) large boulders are essentially immobile unless impacted by tsunami. The first assumption has been challenged by Pérez-Alberti et al. (2012), who demonstrated that in Galicia, northwestern Spain, extensive boulder accumulations arrest the development of the underlying shore platforms. Based on this work, they opined that shore platform gradient increases with the grain size of the material in areas with abundant sediment. The second assumption has been contested by numerous workers who have shown that large boulders are being moved today by high storm waves, often at considerable elevations above the sea (Williams and Hall, 2004; Hall et al., 2008; Hansom et al., 2008; Etienne and Paris, 2010; Fichaut and Suanez, 2011; Goto et al., 2011; Knight and Burningham, 2011; Pérez-Alberti et al., 2012; Shah-Hosseini et al., 2013).

Most recent work on coastal boulders has been concerned with large, often angular clasts either isolated from each other or in fairly small clusters on shore platforms, reef flats, and other rocky surfaces. There has been much less research conducted on clast mobility within beaches consisting of tightly packed and usually rounded boulders (Oak, 1984; McKenna, 2005; Paris et al., 2011), possibly because of the difficulty of collecting sufficient, representative data from large accumulations. Drones, or unmanned aerial vehicles (UAVs), now offer a fairly inexpensive way to acquire such data. This paper is concerned with the mobility of boulders within two boulder beaches in an exposed environment in northwestern Spain, based on data acquired through the use of a small drone (micro-drone). The beach at Laxe Brava was selected for this study because it is one of the best examples of a boulder beach in this region and because of the data (boulder dimensions, etc.) already available from a previous study (Pérez-Alberti et al., 2012). The beach at Oia, which is also one of the best developed along the southern coast of Galicia (south of Vigo to the Portuguese border), was included

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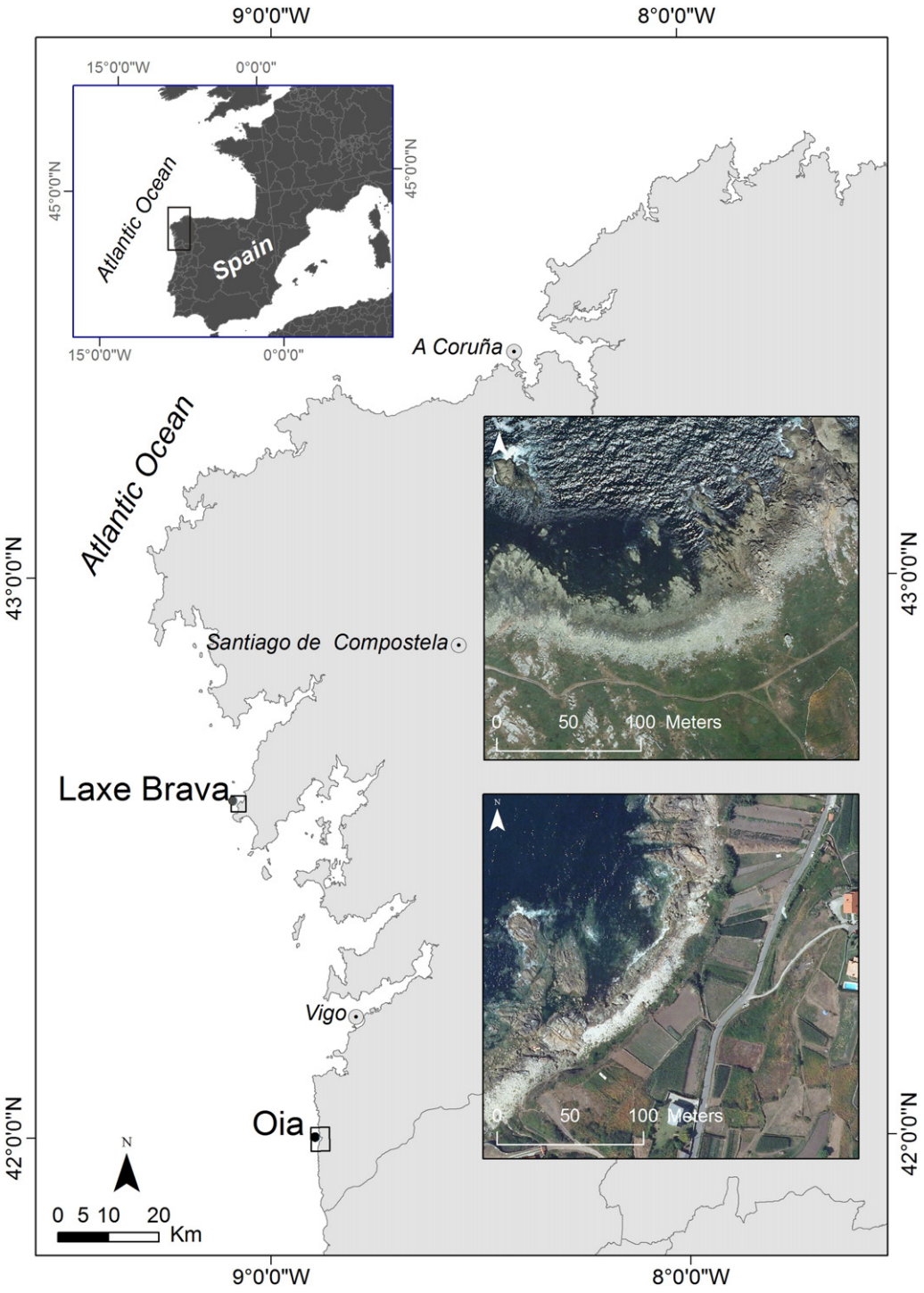


**Fig. 1.** The study areas at Laxe Brava (top inset air photo) on the Barbanza Peninsula and Oia (bottom inset air photo) on the southern coast of Galicia, northwestern Spain.

to compare results from two regions with different boulder provenances (Fig. 1). Boulder data were used to identify and map changes in the location of thousands of mobile and immobile boulders on these beaches, and to relate the changes to boulder size and elevation on the beach. The occurrence and distribution of mobile and immobile boulders were compared over two winters of contrasting severity, with significant differences in the maximum height and energy of the waves.

Boulders are classified in this paper according to the revised Udden-Wentworth scale of Blair and McPherson (1999), whereby the grain size of fine, medium, coarse, and very coarse boulders, as represented by their intermediate axis diameters, range from 25.6 to 51.2 cm (−8 to −9 φ), 51.2 to 102.4 cm (−9 to −10 φ), 102.4 to 204.8 cm (−10 to −11 φ), and 204.8 to 409.6 cm (−11 to −12 φ), respectively.

## 2. The study area

The study was conducted on the southwestern coast of Galicia, in northwestern Spain. The area lies within a Precambrian to Silurian metamorphic belt. The rocks were weathered in the Tertiary under tropical conditions and are generally deeply fractured. The extensive boulder deposits in this region are restricted to granitic shore platforms and they are absent from outcrops of fissile slate and schist. There were