

Figure 2. Bathymetry of Lake Massaciuccoli superimposed on IKONOS satellite image quicklook; with a detailed section of an excavation canal.

Introduction

A survey was undertaken in Lake Massaciuccoli during July 2003 in order to map the bathymetry and bed character of this coastal lagoon. The survey was a combined effort between the University of Southampton, School of Ocean and Earth Sciences, NERC James Rennell Division, and the Istituto di Geoscienze e Georisorse of the Italian CNR-Pisa. The Lake is considered to be highly altered by past anthropogenic activity, and efforts are in place to return it to its original natural state. The management of the Lake is dependant on information on the morphology and dynamics of the system and how these link to the sedimentary, biological, and chemical regimes. The purpose of the survey was to produce a detailed map of the lake for purposes of planning a future joint research campaign on the hydrodynamics of the lake, and the consequent effects on habitat stability. A further objective of the study was to define the volume of water in the Lake for purposes of evaluating the mass balance of fresh water, salt water, sediment, organic matter, and chemical constituents resident in the system at any given time.

The Survey Region

Lake Massaciuccoli is a shallow coastal lagoon situated within the coastal plain of Tuscany, Italy. It is approximately 10 km from the town of Pisa, centred on N 43° 49' 59.5" and E 10° 19' 50.7" and is approximately 2.5 km by 3.5 km in size. Torre del Lago is the closest community to the Lake which is popularly known as "Puccini's Lake". The lagoon is enclosed to the east by coastal plain sediments and to the west by a sandy, wave formed barrier island. The barrier island has been created by the relatively stable position of sea level over the last 6000 years as well as by large supplies of sand from the rivers draining the mountainous region to the east. Much of the sand has been excavated from the vicinity and so the lake is now highly modified by dredging. The lake itself is about 2 m deep on average and very flat, however a labyrinth of canals and flooded excavation pits are evident in the northwest part of the lake, some of which are over 30 m deep.

The lake is protected as a nature reserve by the Region of Tuscany. As such, the preservation and enhancement of habitats is of high priority. The shores of the lake are largely undeveloped and are colonized by reed beds, marshes, and mudflats. The lake supports a wide variety of fauna and flora through controls on fishing, boating, and agricultural discharges into it, however, several drainage channels to the south and west supply nutrient and sediment-charged fresh water to the lake. This surface water is underlain by denser more saline water to produce a well-stratified water column. There are no tides or tidal currents in the lake as the connection to the Mediterranean is regulated. Input of salt water to the system is limited to exchanges in a narrow, artificial canal and possibly through ground water percolation at the western end of the lake. Fresh water input is seasonal and largely restricted to the winter period. Wave activity is largely due to local wind (Grecale) and rarely exceeds 0.5 m in height.

The Survey Setup

A survey was undertaken between 20th and 31st July, 2003. The centre of operations was the Porticciolo, Torre del Lago on the western bank of Lake Massaciuccoli. A yacht was modified to accommodate two echo-sounders, a digital GPS receiver, and a digital sidescan. The two echo-sounders were mounted on downriggers at the stern and interfaced to a PC in the forward cabin. The Garmin® Fishfinder transmitted NMEA083 1.5 codes of depth and water temperature once a second. These strings were captured to the PC using Crosstalk®. The Lowrance® echosounder was interfaced to a Garmin® 12 GPS and logged position, depth, and temperature once a second. Digital sidescan was logged throughout the survey using a Marine Electronics 1640 sonar. The sonar is single channel (starboard) and imaged to a distance of 50 m. Image files were stored automatically at a gain of 9. Parallel lines were run across the lake (ESE-WNW) at a spacing of 20 m.

Track position and navigational logging were undertaken using Garmin® MapSource software. Boat speeds varied between 6-8 km/h; conditions on the lake were calm, humid and very hot (43°C) throughout. The exception took place on 31st July when a strong storm hit the region lasting about 6 hours. It was associated with heavy rain that lowered the air and water temperature about 3°C and increased water column backscatter.

No tidal corrections were applied to the bathymetric data. However a correction for the progressive lowering of lake level (approximately 3cm over the survey period) was applied. The data for this correction were provided by the Istituto Idrografico, derived from an in-situ tide gauge.

Results

Lake Massaciuccoli was surveyed entirely to a line spacing of 20 m (Figure 1). Lines intercalated at 10 m spacing were surveyed on the last day of the survey thus about 20% of the northernmost part of the lake was surveyed at the higher resolution. The excavation north of Porticciolo was also surveyed to a line spacing of 20 m; the main channel leading to the entrance was also surveyed to a distance of about 3 km

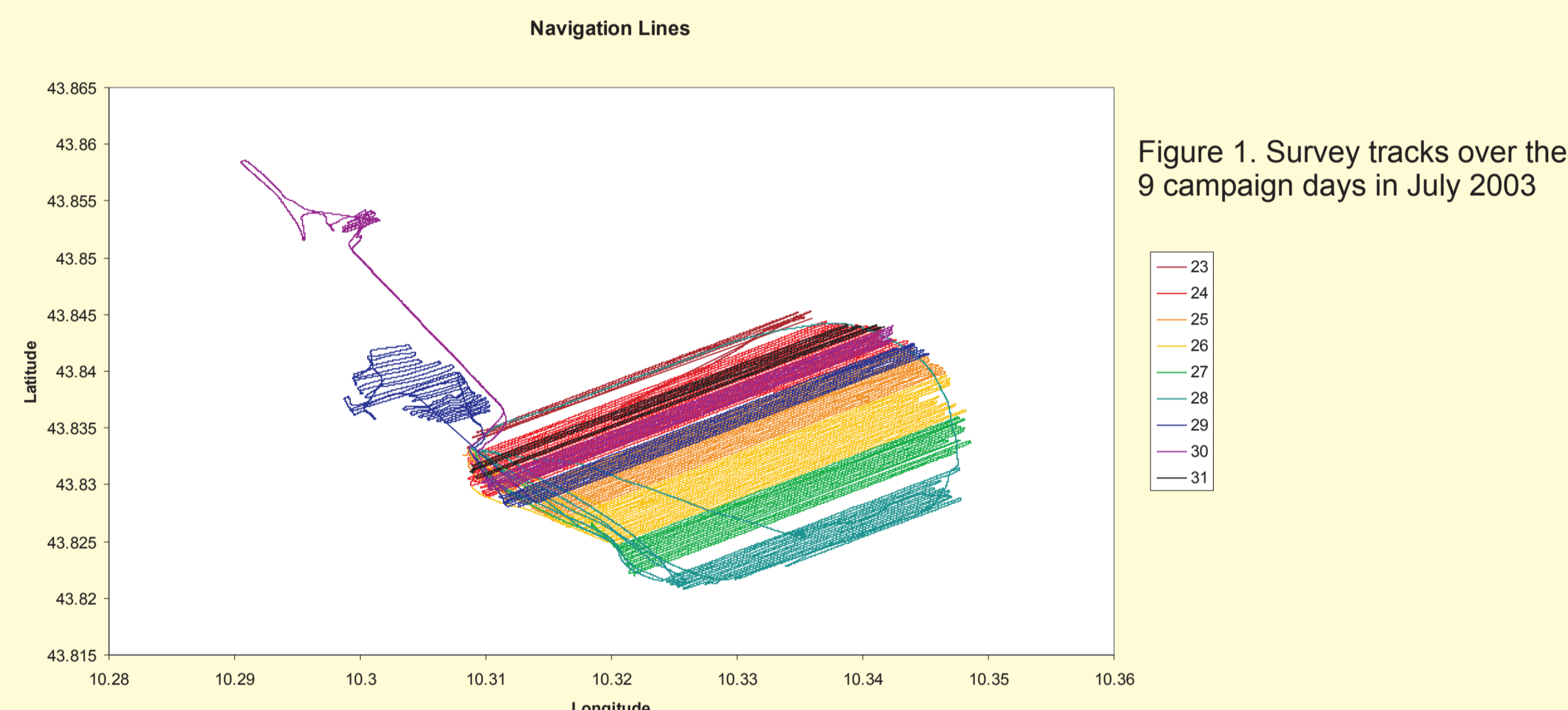


Figure 1. Survey tracks over the 9 campaign days in July 2003

The bathymetry showed the Lake to be extremely flat and shallow (Figure 2). The average depth was 2 m, though isolated depressions were evident off Porticciolo (reaching a depth of 10 m) and along the southern margin of the Lake (reaching depths of 5-6 m). The Lake was shallowest in the east (1 m) and showed a gentle gradient to the west where depths were on average 2 m. The deepest portions of the system were the artificial excavations. These were highly irregular in elevation and varied to depths of 28 m. Vegetation (possibly macrophytes and other lake plants) was prevalent in depths less than 3-4 m and absent below. This depth is likely related to light penetration. In Lake Massaciuccoli the plants were ubiquitous but patchy in distribution. Fish in the water column were prolific, and found either in the region of highest plant abundance, or in the cooler water close to the bed. Surface water temperature of the Lake varied diurnally between 27 and 33°C (Figure 3). No clear pattern in lake temperature emerged due to this large daily effect. Thermal stratification was evident on diving; the lowest water was significantly colder than the surface. Springs of cool water were also detected discharging from the western lake bed. Structure of the water column appeared complex with between 2 and 4 distinct layers evident at time.

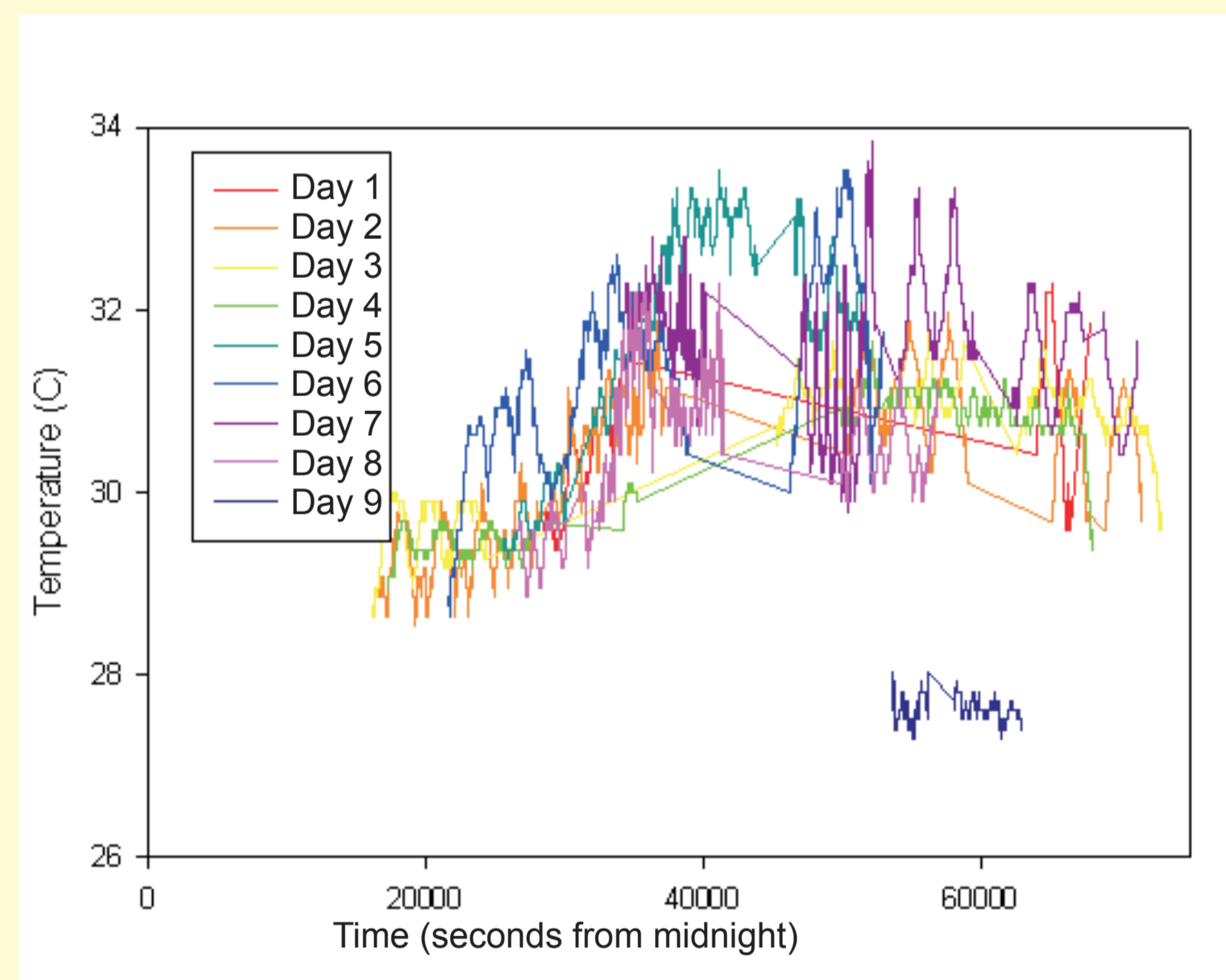


Figure 3. Graph showing diurnal temperature difference throughout the survey. Note the last day's temperature is cooler due to a storm.

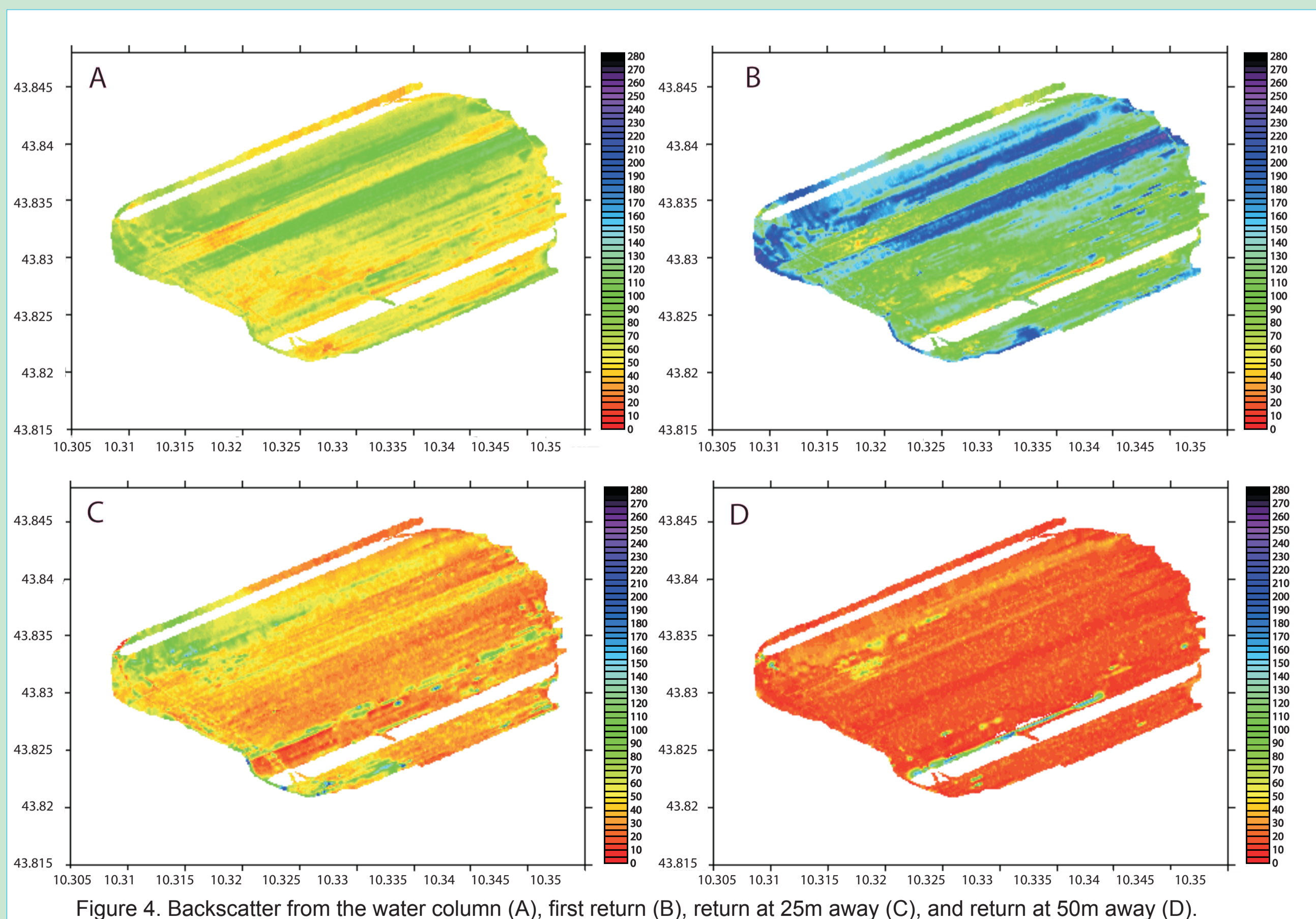


Figure 4. Backscatter from the water column (A), first return (B), return at 25m away (C), and return at 50m away (D).

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Recommendations & Future Activities

This survey was a reconnaissance only primarily undertaken to map the bathymetry and character of Lake Massaciuccoli. The survey line density was planned at 10 m, however, due to time constraints, the survey was largely completed at a line density of 20 m. Due to the overall flat nature of the Lake, the additional lines would not enhance or change the interpretation. However, the cave and canali are highly irregular, deep and host perhaps 50% of the water volume of the system. These need to be completed in order to estimate the resident volume of water. The water column is complex and stratified; CTD profiles together with water sampling is recommended in order to define the structure and the biological/sedimentological constituents of the water column. There appears to be bottom vegetation in the Lake, and, as a result, an abundance of fish. The vegetation appears clearly on the sounders used in this survey, but it has not been mapped in detail. A survey to map macrophyte distribution is thus recommended.

The results of this study underline the relevance of the areas affected by sand excavation both for the mass balance of the lake and for the type of ecosystem; further activities, not yet carried out but for which **funding is currently being sought**, are:

- a comparison with measurements of water parameters taken during complementary campaigns;
- the completion of the survey and its use for the implementation of a dynamical model of the lake circulation and sediment transport, and in support of a program for the rejuvenation and careful management of the area;
- an airborne remote sensing campaign to map the water quality of the lake to be carried out in combination with further side-scan radar investigations.