

## Article

# First Perceptions of Hydroperiod Mapping and Assessment of Shallow Waters in Coastal Landscapes by Drone-Based Monitoring Activities: A Remote-Sensing and GIS Approach

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**Abstract:** Beyond the importance of ponds for aquatic and terrestrial life, pond networks seem to be crucial to providing a vital spatial resource in response to global climate change for all migrating and spreading taxa. Additionally, ponds offer sustainable solutions to issues of concern in water management, such as nutrient retention, rainfall interception, or carbon sequestration. Although the ecological role of shallow waters seems clear, significant work must be performed to set future guidelines and actions towards their conservation. The main aims of the present study are to (i) georeference all small temporary wetlands within the Tyrrhenian central Italy coastal area, (ii) evaluate their hydroperiod, and (iii) calculate their surface size variability. We found 137 wetlands, 53 of which were temporary and contained listed habitats. Each wetland's status was assessed in relation to land use and proximity to stressors (e.g., urban centres, railways, roads) while observing the relationship between pond occurrence, lithology, and permeability. Amongst the detected wetlands, we selected and monitored 21 temporary ponds (homogeneously distributed within the study area) for 12 months using images collected by the non-professional drone Parrot Bebop 2. All images were then acquired in ArcGIS to georeference all temporary ponds. The analysis confirmed that the majority of the surveyed ponds are in close proximity to roads and tracks, which might have significant impacts on the preservation of such fragile habitats. Moreover, despite the wide variability of hydroperiod duration, the greater part of the pools fill with water in autumn and dry in summer, in alignment with the Mediterranean climate. This preliminary study allowed for the creation of the first temporary ponds' database, which is useful for monitoring their status in central Italy and planning further studies to assess eventual detrimental effects caused by human-mediated activities.

**Keywords:** environmental assessment; freshwater ecosystems' conservation; Mediterranean wetlands; unmanned aerial vehicles (UAVs)



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## 1. Introduction

Wetlands include several shallow aquatic habitats [1], which are considered amongst the most biodiverse ecosystems on Earth [2] and provide diverse services to humankind [3,4]. Intermittently flooded wetlands are part of the hydrological landscape worldwide and, even if generally small (less than 10 ha) and shallow (no more than six m), these temporary habitats occur in endorheic depressions located in a diversity of landscapes in which they are isolated from permanent water sources [5]. Their key feature is the cyclical alternation of dry and wet phases, the latter being sufficiently long to drive the establishment of peculiar biocenosis, [6] thereby contributing strongly to regional biodiversity [7], sometimes even more than large permanent water bodies [8]. In fact, temporary wetlands host generalist species, as well as unique species adapted to extremely dynamic environmental conditions,

which often have biphasic or complex life cycles [9]. Additionally, temporary wetlands act as aquatic stepping stones in terrestrial matrices and provide foraging and resting habitats for migrating species that spread for reproduction or feeding and then return to deep-water habitats to hibernate [10]. Many mammals, amphibians, reptiles, and birds use the abundant carbon resources (i.e., egg masses, amphibian larvae and adults, invertebrates, algae, and plants) to supplement their diets, especially after winter [11]. The presence of temporary wetlands is important for reducing peak floodwater flows and contributing to groundwater recharge or discharge [12]. Temporary wetlands also ensure lag, sink, and source functions [13] that have effects on the physical, chemical, and biological status of downstream waters. Furthermore, these habitats take part in the biogeochemical cycles of carbon sequestration [14], denitrification, sediment retention, pesticide transformation, and absorption of phosphorus and other aquatic pollutants [15]. Such functions are enhanced on wetland edges [16] because temporary ponds have disproportionately large perimeters and are more reactive per unit area than other wetlands or adjacent soils and forests [17]. While estimates and attempts to capture regional contributions of temporary wetlands are coarse, current data suggest that temporary wetlands may play a significant role in hydrologic and biogeochemical processes beyond the pool itself [18,19].

Unfortunately, temporary wetlands have been neglected for a long time [20] and are disappearing at an alarming rate worldwide [21,22]. Due to their small size and shallowness, these habitats are poorly preserved and easily destroyed or degraded by human activities such as urbanisation, agriculture, livestock (which turns temporary wetlands into permanent pools [23]), water extraction, sedimentation, and toxic pollution [24].

Loss and degradation of wetlands and their ecosystem services [25] are accelerated further by climate change and the introduction of invasive species, both of which act as environmental constraints driving extreme shifts in aquatic invertebrate diversity and plant species composition [26]. Therefore, the interaction of these threats highlights how careful monitoring and unambiguous management strategies of these systems are crucial [27,28].

Limited awareness of and incomplete databases on temporary wetlands make their management more difficult, and public understanding of their functions and value is scarce, diminishing support for public conservation actions [16,19,29]. Despite the urgent need for wetland protection, monitoring and conservation are often hampered by inconsistent and contradictory international agreements and national policies, thus making their ecological evaluation difficult [30,31].

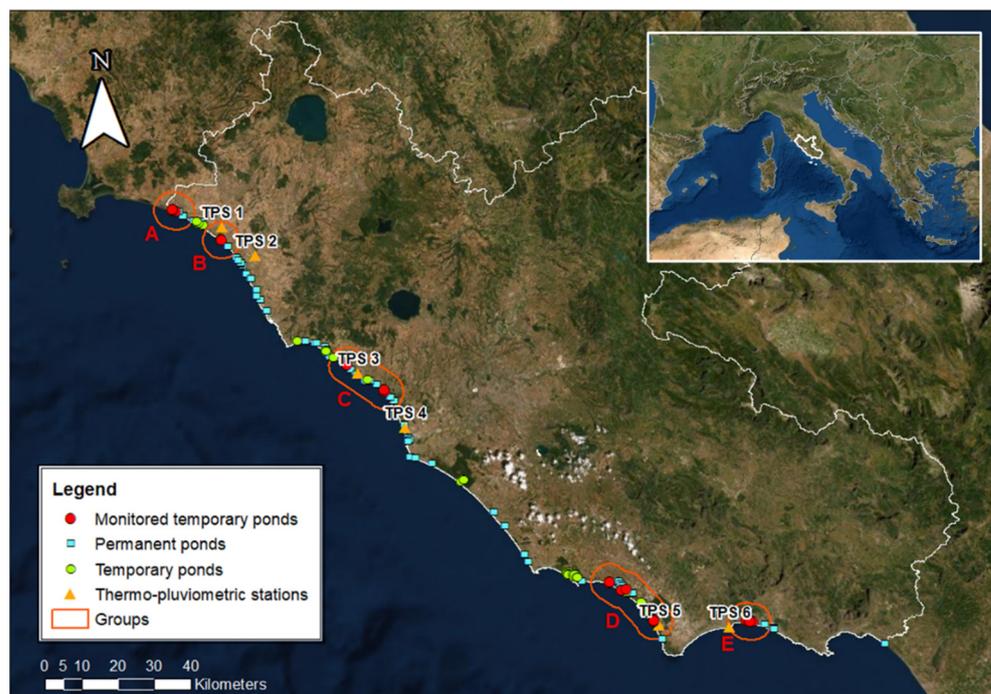
While innovative approaches are being tested for the assessment of large, permanent water bodies, similar techniques are lacking for the monitoring of temporary ponds. Indeed, recent studies have successfully used machine-learning methods and satellite remote-sensing time series analysis for spatio-temporal monitoring of the water coverage and quality of lakes and aquaculture ponds [32–36]. However, the implementation of such techniques on small temporary ponds has been hampered by the limited extent and dynamism of these ponds due to short water detention. To ensure the effective management of temporary wetlands (both at the individual and landscape scale), spatial inventories and ecological assessments of the status of these habitats are essential, as well as information about their adjacent terrestrial matrices [37–39]. From this perspective, the application of unmanned-aerial-vehicles (UAVs)-based remote-sensing techniques [40] in studies carried out in several coastal Mediterranean regions [41] successfully helps to document both the occurrence and lifetime of temporary ponds [22].

In this context, the main aims of the present study are to (i) georeference all temporary wetlands within the Tyrrhenian central Italy coastal area; (ii) relate ponds to their proximity to stressors, land use, and lithology; (iii) calculate their water surface size variability; and (iv) evaluate their hydroperiod (i.e., water residence time, expressed in the number of days per year). The main purpose of this study is to know and describe the status of temporary ponds in central Italy, to highlight some of their hydrodynamic properties, and to provide a baseline for future comparisons.

## 2. Materials and Methods

### 2.1. Subsection

The temporary ponds investigated were located within the coastal area of Latium (central Italy). Surveys were carried out no more than 1 km away from the shore along a 360 km shoreline, for a total surface of about 360 km<sup>2</sup> (Figure 1). The mean distance of the ponds from the shore was 550 m.



**Figure 1.** Permanent (light blue squares) and temporary (green and red circles) coastal wetlands within the study area. The 21 selected and monitored Mediterranean temporary ponds are indicated with red circles and divided into five groups according to proximity amongst pools and land use context: A, pastures; B, agricultural with grasses; C, reserves; D, urban; E, mixed agricultural and pastures.

Before starting field surveys, a preliminary observation was conducted using Google Earth satellite imagery (Google Earth Pro software, version 7.3) to detect both permanent and temporary coastal water bodies. To understand their actual temporariness, surface size changes over time were observed by using the Historical Imagery routine. However, this approach is not free of uncertainties and biases, as not all historical images allow such an analysis because of different sensors' spatial resolution and cloud coverage.

After the preparatory virtual checking, field inspections of the study area were carried out to assess the effective temporary nature of the selected water bodies. Two sessions of 14-day inspections were performed on the entire coastal region in early spring 2017 and late summer 2017. Spring inspections were essential to verify the actual presence and spatial arrangement of water bodies in order to assess their accessibility (given that many temporary wetlands were located within private and/or agricultural areas with limited or forbidden access). The second session was carried out to ensure that all ponds identified during the first session went dry during the summer, confirming the temporariness of the water bodies, whose coordinates were subsequently recorded using a GPS device.

A subset of temporary ponds (Figure 1) was selected over the entire Latium coast to be monitored monthly from January to December 2018 to study their hydroperiod and surface area. To this end, the Parrot Bebop 2 unmanned aerial vehicle (UAV) was used to take aerial images during each monitoring session. The UAV flight settings for the surveys

included altitudes ranging from 70 to 145 m above ground, with a 90° camera angle with respect to the pond centre.

During each monitoring session, pH, water and air temperature ( $T_w$  and  $T_{atm}$ , respectively), electric conductivity (EC), and dissolved oxygen ( $O_2$ , in mg/L and %) were measured using a Hach HQ40d Portable multi-parameter probe (as required by the Habitat Directive guidelines). Furthermore, water samples were collected at each sampling site for spectrophotometric analysis of nitrate ( $NO_3^-$ ) and phosphates ( $PO_4^{3-}$ ).

Data on temperature and precipitation in proximity to the surveyed coastal wetlands were obtained from six coastal meteorological (thermo-pluviometric) stations (Figure 1).

An ordination through principal component analysis (PCA) was performed by using all the physico-chemical descriptors to observe eventual differences in water quality amongst the investigated temporary ponds.

Furthermore, temperature and precipitation data from the closest stations were downloaded to assess the relationship between the thermo-pluviometric diagrams and pond size variation.

## 2.2. Image Processing and Analysis

Image processing and analysis were performed using ESRI's ArcGIS 10.1 software. Spatial data from multiple open-access databases were collected to gather information about the surrounding area of all the ponds detected within the coastal area of Latium. Data on the lithology and land cover (Corine Land Cover) were downloaded from [SINAnet.ispraambiente.it](http://SINAnet.ispraambiente.it) (accessed on 26 January 2020). By applying the intersect geoprocessing tool available on ArcGIS, information on soil type and land cover was assigned to each pond. Moreover, locations of roads, railways, airports, and urban areas were downloaded from [OpenStreetMap.org](http://OpenStreetMap.org) (accessed on 7 February 2020), and the proximity analysis tools of ESRI's ArcMap were used to assess which of these landscape elements may represent the main physical anthropogenic disturbances threatening coastal ponds in central Italy.

All aerial images of the monitored temporary ponds were georeferenced using an average of six ground control points. After georeferencing, UAV images were visually interpreted to outline polygon features of the ponds' shape. In this way, it was possible to estimate the ponds' size with the Calculate Geometry tool and to evaluate the change in the surface size of the temporary water bodies over time. In particular, a correlation analysis was performed to evaluate the relationship between the wet period length (expressed by the number of months) and the largest surface size (in ha) of the monitored coastal ponds.

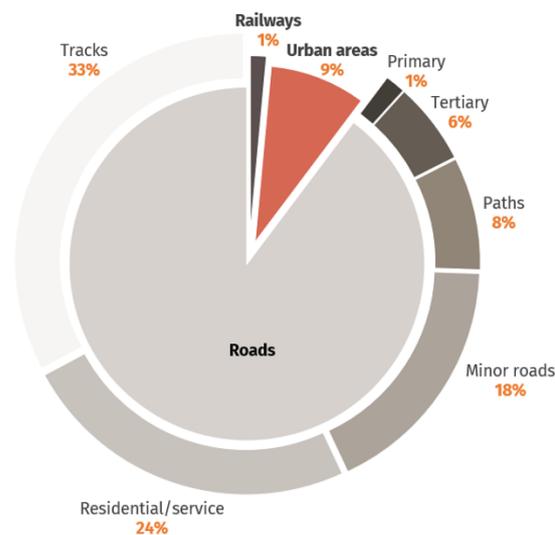
## 3. Results

This case study conducted a census of 137 permanent and temporary natural ponds, which are often doomed to disappear due to intrinsic factors such as their scattered and isolated distribution, as well as extrinsic ones such as urban development.

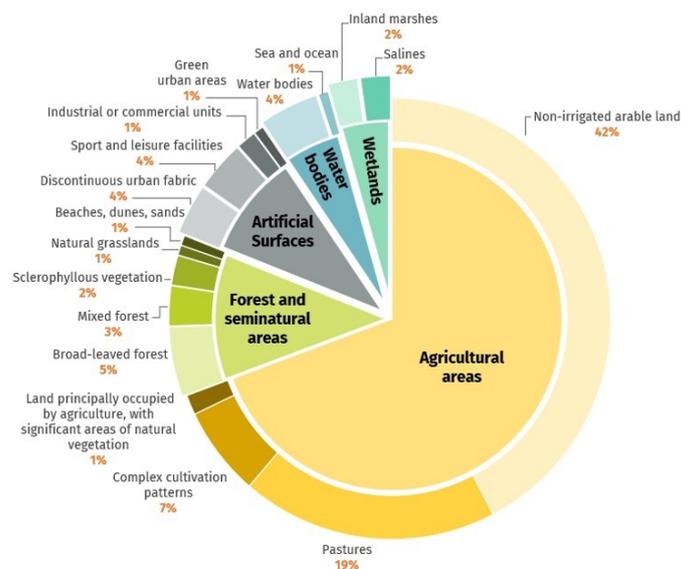
Further analysis demonstrated that the most frequent threats in close proximity to the surveyed ponds were roads, especially walking paths and residential roads (Figure 2), which is consistent with the results from previous studies [42]. Indeed, increasingly accelerated urbanisation based on housing or/and road development projects has consequently led to the extinction of numerous ponds in the Latium area.

In addition, most of the ponds located in non-natural areas are subject to intense anthropogenic activities, such as artificial surfaces, agricultural land, and pastures (Figure 3). Water drawn from the ponds is used for various purposes, such as the irrigation of agricultural land, the watering of livestock, and domestic use.

The last part of this case study concerned the several types of substrata likely to give rise to pools. The majority of the investigated ponds occurred on water-permeable soils (Figure 4) on account of their contiguity with the sea.



**Figure 2.** Relative abundance of the fundamental stressors to the detected coastal ponds. Due to their substantial differences, the various road types are made explicit (outer ring).



**Figure 3.** Frequency of land cover types with the occurring coastal ponds. Inner circle: level 1 Corine Land Cover classes. Outer ring: level 3 Corine Land Cover classes.

The census carried out in this study highlighted the presence of 137 coastal wetlands, 53 of which were identified as temporary pools (Figure 1), where three types of habitats listed in the Habitat Directive were observed: 3120 (Oligotrophic waters containing very few minerals, generally on sandy soils of the West Mediterranean, with *Isoëtes* spp.), 3130 (Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or the *Isoëto-Nanojuncetea* communities) and 3170\* (Mediterranean temporary pond, MTP), the latter being considered a priority habitat from a management and conservation viewpoint.

Amongst these habitats, only MTPs have been monitored over time. Due to the large size of the study area, 21 coastal MTPs were selected and monitored for 12 months in order to study both hydroperiod and surface size. These ponds have been divided into five groups as shown in Figure 1 on the basis of proximity amongst pools and land-use context: A, pastures; B, agricultural with grasses; C, protected areas/natural reserves; D, urban; E, mixed agricultural and pastures.

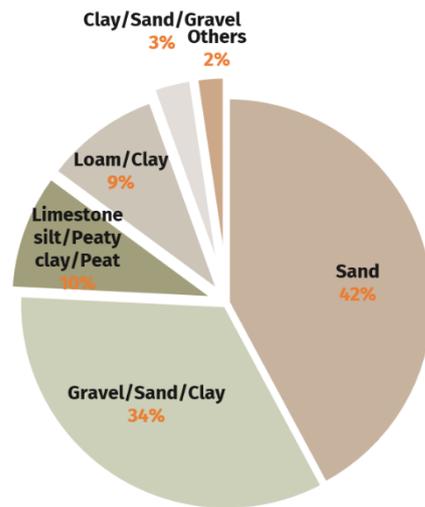


Figure 4. Frequency of lithological types of soil across the surveyed ponds.

The surface size values and the hydroperiod duration of each pool showed a broad variability within and amongst groups for both descriptors (Figure 5).

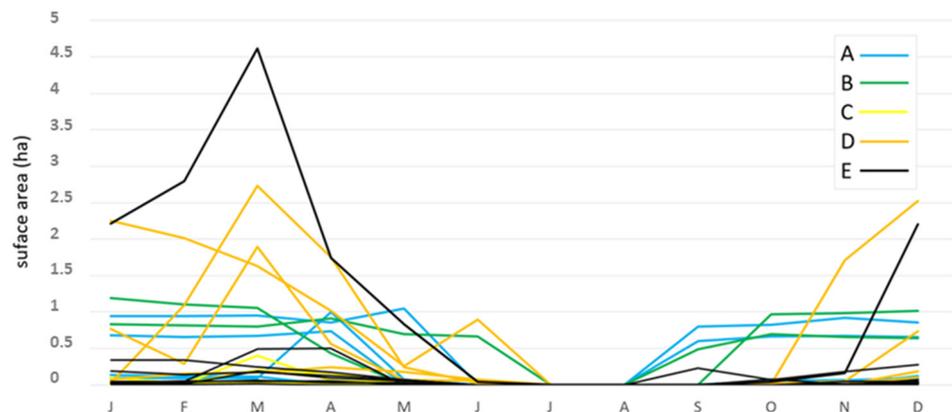
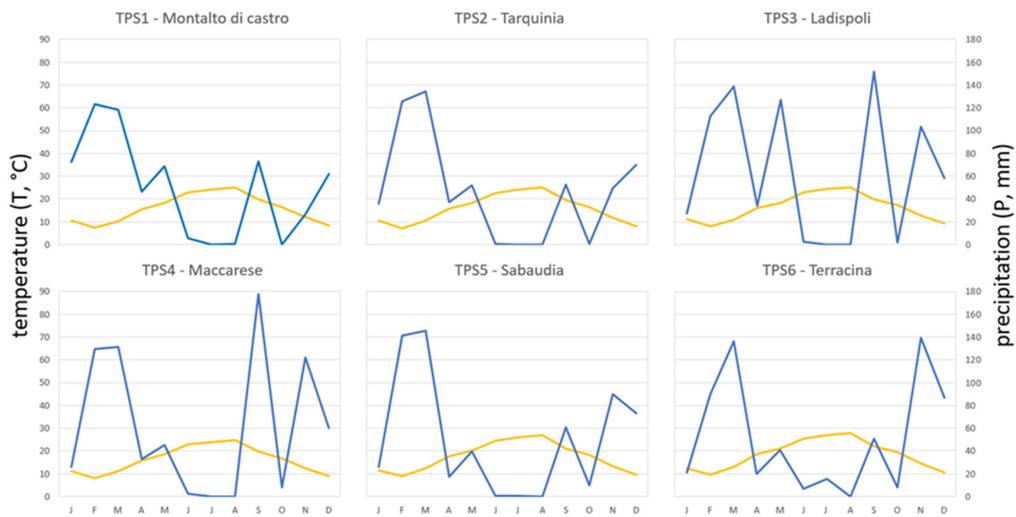


Figure 5. Surface size variation (in ha) of the monitored Mediterranean temporary ponds during the study period. The monitored coastal ponds are grouped as indicated in Figure 1: A, pastures; B, agricultural with grasses; C, reserves; D, urban; E, mixed agricultural and pastures.

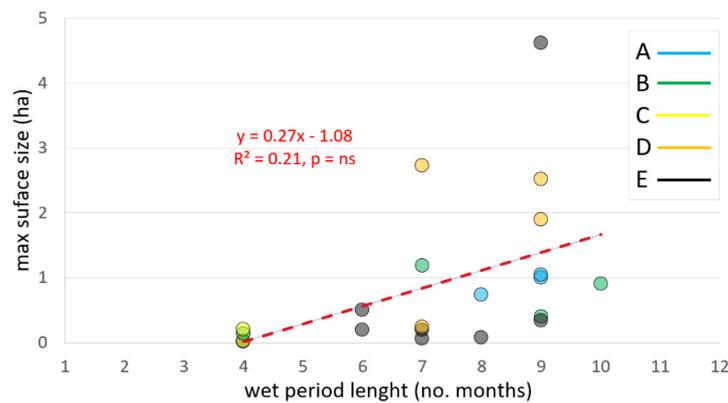
Although each MTP had its hydroperiod, July and August were always the months of drought for all the monitored temporary ponds, forming the period during which the highest T values and the lowest precipitation values were recorded (Figure 6). In some ponds, the dry period began in June, and in most of the MTPs, the dry period ended in September, although there were also cases of dry periods ending in January.

A non-significant correlation between the hydroperiod (expressed by the number of wet months) and the maximum surface size (in ha) is shown in Figure 7.

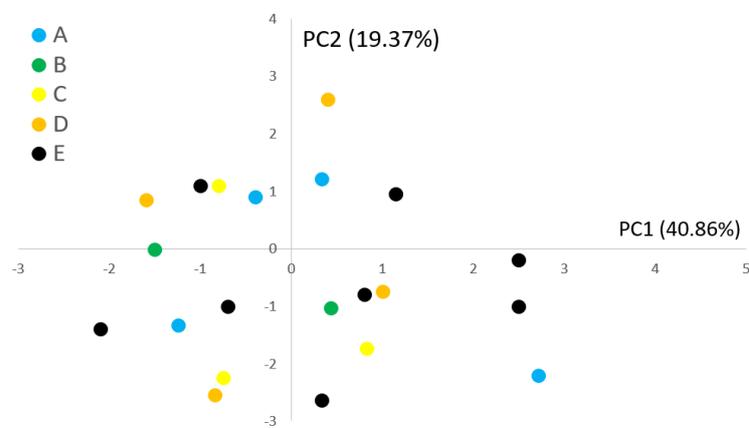
From a physico-chemical point of view as well (Table 1), the investigated MTPs showed a broad variability within each group and overlap between groups, as also described by the output of PCA ordination (Figure 8).



**Figure 6.** Plots obtained using data of temperature (T, °C, in orange) and precipitation (P, mm, in blue) from the six coastal meteorological thermo-pluviometric stations (TPS) indicated in Figure 1.



**Figure 7.** Correlation between the wet period length (months) and the max surface size (ha) of the 21 monitored coastal ponds. The monitored coastal ponds are grouped as indicated in Figure 1: A, pastures; B, agricultural with grasses; C, reserves; D, urban; E, mixed agricultural and pastures.



**Figure 8.** Plots created using the values of the first two principal components obtained by PCA ordination of the physico-chemical data reported in Table 1 and surveyed in the 21 monitored coastal ponds grouped as indicated in Figure 1: A, pastures; B, agricultural with grasses; C, reserves; D, urban; E, mixed agricultural and pastures.

**Table 1.** Physico-chemical measurements of the 21 monitored Mediterranean temporary ponds within the study area. Parameters in alphabetical order: EC = electric conductivity ( $\mu\text{S}/\text{cm}$ );  $\text{NO}_3^-$  = nitrate ( $\text{mg}/\text{L}$ );  $\text{O}_2$  = dissolved oxygen ( $\text{mg}/\text{L}$ , and %);  $\text{PO}_4^{3-}$  = phosphate ( $\text{mg}/\text{L}$ );  $T_{\text{atm}}$  = atmospheric temperature ( $^\circ\text{C}$ );  $T_{\text{w}}$  = water temperature ( $^\circ\text{C}$ ).

| Group | Site | $\text{O}_2$ (mg/L) | $\text{O}_2$ (%) | $T_{\text{atm}}$ | $T_{\text{w}}$ | pH   | $\text{PO}_4^{3-}$ | $\text{NO}_3^-$ | EC   |
|-------|------|---------------------|------------------|------------------|----------------|------|--------------------|-----------------|------|
| A     | 1    | 2.12                | 3.89             | 15.71            | 13.83          | 8.12 | 1.88               | 4.22            | 1.07 |
|       | 2    | 2.67                | 3.99             | 16.12            | 13.96          | 8.01 | 1.56               | 3.45            | 1.86 |
|       | 3    | 2.80                | 3.19             | 14.87            | 10.02          | 7.74 | 0.59               | 0.39            | 2.63 |
|       | 4    | 3.33                | 4.97             | 15.55            | 10.97          | 7.80 | 1.45               | 0.46            | 2.12 |
| B     | 1    | 3.19                | 4.86             | 16.69            | 12.28          | 8.01 | 1.71               | 3.20            | 2.02 |
|       | 2    | 3.21                | 4.97             | 14.77            | 11.03          | 7.03 | 1.89               | 3.50            | 2.8  |
| C     | 1    | 2.01                | 3.68             | 17.84            | 14.85          | 7.50 | 1.77               | 3.69            | 1.09 |
|       | 2    | 2.66                | 3.13             | 20.12            | 17.56          | 6.92 | 1.55               | 3.41            | 1.31 |
|       | 3    | 1.98                | 2.12             | 19.34            | 16.02          | 7.78 | 1.41               | 4.11            | 2.07 |
| D     | 1    | 3.03                | 4.93             | 14.76            | 11.99          | 7.44 | 1.15               | 2.41            | 1.06 |
|       | 2    | 3.46                | 4.04             | 16.82            | 14.77          | 7.64 | 0.11               | 0.62            | 1.62 |
|       | 3    | 2.03                | 3.83             | 15.07            | 10.29          | 8.04 | 0.24               | 0.53            | 2.02 |
|       | 4    | 1.78                | 2.33             | 15.25            | 12.54          | 7.70 | 0.24               | 0.44            | 2.86 |
| E     | 1    | 2.57                | 3.21             | 15.29            | 12.85          | 8.10 | 1.45               | 4.56            | 1.66 |
|       | 2    | 2.69                | 3.44             | 15.44            | 23.31          | 8.10 | 0.86               | 2.10            | 1.54 |
|       | 3    | 2.84                | 3.52             | 15.36            | 11.17          | 7.55 | 0.79               | 1.88            | 1.61 |
|       | 4    | 2.22                | 3.59             | 12.41            | 9.14           | 7.35 | 0.27               | 1.88            | 2.49 |
|       | 5    | 4.54                | 5.70             | 13.22            | 10.78          | 7.55 | 0.67               | 0.58            | 2.08 |
|       | 6    | 2.37                | 3.30             | 12.96            | 10.63          | 7.14 | 0.12               | 0.68            | 1.56 |
|       | 7    | 2.66                | 3.30             | 13.44            | 10.96          | 7.82 | 0.14               | 0.75            | 1.87 |
|       | 8    | 3.07                | 4.23             | 13.48            | 11.24          | 7.33 | 1.12               | 2.38            | 1.67 |

#### 4. Discussion

The main aim of the present study was to initiate and design a monitoring plan for temporary aquatic habitats that are of naturalistic concern but that have been neglected for a long time despite their inclusion in the Habitat Directive. Indeed, detailed wetland inventories are lacking in large areas of the world (e.g., Asia, South America) [26], and overall, small wetlands are often disregarded or not identified in regions where inventories are made [43].

In this study, our inspection and monitoring activities highlighted the great importance of these habitats within the coastal water network. In fact, of all coastal water bodies, more than a third (53/137) were temporary, and these were evenly distributed within the study area. Their occurrence, from autumn to spring, allows the increased dispersion of many organisms that do not find available habitats during the dry months. Indeed, temporary ponds are often used as breeding spots for amphibians (see Introduction) because the distribution of such wetlands guarantees continuity along the entire coast and serves as an important ecological corridor for both native and alien organisms in dispersion and/or migration, such as the smooth newt *Lissotriton vulgaris* (observed within ponds from group C) and the non-native red swamp crayfish *Procambarus clarkii* (groups D and E).

From a conservational point of view, the finding of three different types of habitats listed in the main international conventions for environmental protection is significant, with particular reference to the priority habitat 3170\*, which was the most abundant habitat on the entire coastline. Mediterranean temporary ponds are a peculiar type of temporary wetlands, which mainly occur around the Mediterranean basin in southern Europe and North Africa, but also in other regions with a Mediterranean climate (i.e., mild and rainy winters, hot and dry summers) [44]. Mediterranean temporary ponds in southern Europe are an EU Priority Habitat under the auspices of the Habitats Directive, and special protections apply in several Mediterranean countries [28,45]. These very shallow ponds are present only during winter and late spring and harbour several rare or threatened species of plants, amphibians, and invertebrates listed in international conventions (the Habitats Directive, the Bern Convention, and the IUCN Red List) [9]. The preservation of such habitats is also a priority of the Mediterranean Wetlands Strategy, which aims at “stopping

and reversing the loss and degradation of Mediterranean wetlands as a contribution to the conservation of biodiversity and sustainable development in the region" [1].

In this study, only MTPs have been monitored over time in order to survey both hydroperiod and surface size. To collect information on occurrence and surface size, the use of UAVs was preferred to satellite images because of limitations in data availability in adverse atmospheric conditions and sensors' spatial resolution [46]. However, the current progress of remote-sensing technologies appears promising for improving the detection and mapping of small wetland features [46,47].

Over the last decade, the use of drones for both civilian and scientific purposes has aroused growing interest, so much as to mark the beginning of a new era of remote sensing [48] in the study of the environment [49]. Indeed, drones represent a relatively risk-free and low-cost way to observe natural phenomena rapidly and systematically at high spatial and temporal resolutions [50]. For these reasons, drones have recently become a major trend in wildlife research [51,52] and management [53–55].

As temporary ponds are fluctuating, highly dynamic systems, well-designed sampling protocols exploiting remote-sensing systems are required to incorporate such temporal variability [56]. In this study, the use of remote-sensing techniques was necessary to describe the variation in size and hydroperiod of the investigated temporary ponds. The surface size values and hydroperiods of each pond showed a broad variability of both descriptors within and amongst groups. Moreover, our results indicate that these two descriptors are not statistically correlated, which suggests that the hydroperiod is independent of the size of the pond. When considering the physico-chemical analyses carried out on the monitored water bodies, this study shows that the ponds do not show significant differences. In particular, the hydroperiod, the size, and the physical and chemical conditions do not seem to show evident patterns related to geographical position and/or environmental conditions. Most likely, future monitoring protocols on the status of temporary pools will also have to take into account the presence of water in the subsoil and exposure to weather conditions (mostly related to wind and solar radiation).

The characteristic features of temporary ponds are their small size (generally no more than five ha large) and shallow depth (often only a few decimetres deep). Such small water volumes are subject to strong diurnal and seasonal fluctuations in abiotic parameters such as pH, oxygen, nutrients, temperature, and electrical conductivity [6,9]. Water levels also tend to vary widely between and within years, depending on climate conditions [57,58], which implies that spot measurements of water quality parameters only provide information on the current state of the wetland, sometimes neglecting significant temporal fluctuations. The timing of these measurements is therefore critically important for the outcome of the assessment. The seasonal fluctuations in abiotic conditions also result in a considerable turnover of the animal and plant communities with clear successional phases, each represented by a distinctive group of organisms [57,59,60].

The hydroperiod strongly affects the community composition since it represents the time window during which organisms must colonise, grow, and reproduce [61]. In addition, interannual differences in environmental conditions can lead to different communities than in previous inundations [57], which can play a significant role in the evaluation of ecological integrity of temporary wetland ecosystems [62,63].

## 5. Conclusions

Although temporary wetlands are the main water sources in (semi)arid regions and often provide habitats for unique biodiversity, monitoring programmes such as those required by the Water Framework Directive are missing to date. This is surprising since temporary ponds may be considered suitable indicators of environmental modifications related to detrimental effects caused by actual progressive climate changes.

Managing and preserving temporary wetlands and their ecosystem services means evaluating their conservation status, and the first step towards this objective is to improve knowledge of their distribution and hydrodynamism, as well as their relation to land use.

Therefore, in the present study, we georeferenced all small temporary wetlands within the Tyrrhenian central Italy coastal area, evaluated their hydroperiod, and calculated their surface size variability. Moreover, the wetlands' statuses were assessed in relation to land use and proximity to stressors by assessing the relationship between pond occurrence, lithology, and permeability.

Our main findings are that most of the surveyed ponds are in close proximity to roads and tracks, which might have significant impacts on their conservation. Furthermore, such habitats could act as models for monitoring the effects of climate change through hydroperiod assessment. However, the very dynamic hydroperiod of such water bodies leads to rapid changes in shape and size within a year, making their monitoring difficult and their mapping complicated. Indeed, the high dynamism, together with the small size of such types of ecosystems, may have hampered their extensive identification. Several temporary ponds may have been missed during the preliminary Google Earth visual inspection. Although urgently needed, no dedicated protocols are now available for the monitoring of such types of ecosystems. However, all of the above can be explained by the fact that the degree to which areas are selected for monitoring and protection is inversely proportional to their relative "mappability" [64].

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