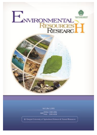

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The ecological boundaries of semi-arid wetland using a protocol enhanced by bird indicators: The international Alagol wetland of Iran

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Abstract

Wetlands as water resources have a special place in the semi-arid plateau of Iran and boundary determination is necessary for their effective conservation and conflict resolution among stakeholders that are dependent on these resources. Determination of the wetland boundaries should be commensurate with environmental features affecting on it which normally extend beyond water extent. Ecological wetland boundaries are normally affected by water extent, hydric soils, and obligate water plants that constitute a normal protocol for wetland boundary determination. Also, we add wetland dependent fauna with special emphasis on birds to these three features to get to a more ecologically integrated boundary determination. Thus, in our approach, boundary determination requires information on indicators relating to soil, hydrology, vegetation, and wetland dependent fauna. We carried out field sampling of the Alagol wetland during which we recorded hydrology, percent vegetation cover, plant species, soil parameters, and dependent/loving birds within 1000 m radius of the initial water body. The results, determined the seasonal and temporary boundaries, and finally the ecological aspects helped in better boundary determination and suggestions for an integrated protection of Alagol wetland. We also suggested a buffer for protection of other wetland birds in areas further than 1000 m from the initial boundary to make sure the resulting boundary stays afar from violations.

Keywords: Ecological indicators, Borders, Mapping, management.

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1. Introduction

Wetlands have a special place as water resources in the semi-arid plateau of Iran. Wetland boundary delineation is an attempt to determine the accurate line where the wetland ends and the upland begins. The establishment of a wetland boundary which should be ecological rather than solely hydrological, is an important step in preserving wetland functions and values. This boundary determination is also required in land-use evaluation processes to ensure that legitimate development proposals are judged fairly and equitably. In other words, identification of the ecological boundary is important for wetlands to ensure proper protection of their biodiversity and definition of buffer zones (Lalibert *et al.*, 2007). This also makes it possible to restrict improper land cover changes in their vicinity. Wetland boundary is normally beyond the current water area, because most inland wetlands dry up at different times of the year (Tiner, 1991). As a result, the boundary of water is changeable and cannot be used solely as a proper criterion for wetland boundary determination. In addition, according to Article 6-aof the Ramsar Convention, legal boundaries for the Ramsar Convention wetlands should be introduced. In doing so, the wetland boundary map has to be up-dated every few years (RIS, information Sheet on Ramsar Wetlands, 2009-2012).Furthermore, the Convention on International Wetlands emphasizes upon conservation of wetlands primarily as a habitat for water birds. Several researchers incorporate vegetation, soils, and hydrologic properties into wetland delineation procedure.

Wetlands usually possess three zones saturated for different lengths of time, although these zones may not be present in all wetlands. The central part of the wetland, where it is wet all year round, is the permanent zone. This area is surrounded by the seasonal zone, which is saturated for a significant duration of the rainy season and at least three months per annum. The temporary zone surrounds the seasonal zone, and is saturated for only a short period of the year, less than three months per annum. Both the soil and vegetation will change from one zone to another (Department of Water Affairs and Forestry, 1999). In our study, seasonal and temporary boundaries were delineated in the wetland based on topography, soil and vegetation sampling, and focusing on terrestrial animals. Temporary boundary delineation helps to complete the process of the ecological wetland boundary determination.

Segal *et al.,* (1987) mentioned soil factors and vegetation determined visually and through vegetation analysis along transects from water towards uplands for boundary demarcation. Zedler and Cox (1985) advocated the use of a multi-parameter approach to wetland delineation, and Jackson *et al*. (1995) noted that soil, vegetation and topography are the main indicators of wetland areas. Furthermore, Dewey *et al.* (2006), Yin & Lu (2006) suggested two influential parameters in identifying wetlands including plants and soil saturation duration. Laliberte *et al.* (2007) established twelve transects on the sloping rims of each of six bays in north eastern South Carolina to characterize the community gradient as well as important environmental factors producing the gradient. They estimated ecological boundaries using hydrology, soil properties, and plant species in these transects.

In our study, locating ecological wetland boundaries for regulatory purposes was composed of a two-step process. First, soils, vegetation, and hydrology are examined and a water boundary line is flagged between the wetlands and uplands as wetland boundary. Second, relevant birds as the focal species and as significant indicators of wetland ecology within a radius of the initial ecological boundary of the wetland are studied and included into the boundary to complement the process of boundary determination. Ecological wetland boundaries encompass the water extent (permanent, seasonal, and temporary), soil and plants, and animals dependent upon wetland habitats. Ecological boundaries are defined as areas of relatively steep environmental or community gradients (Cadenasso *et al.,* 2003). As ecological boundaries of wetlands may regulate the flow of energy, materials, and organisms between wetlands and adjacent uplands, it is important to accurately characterize these boundaries with the goal of protecting or improving wetlands' integrity (Holland, 1996).

Iran enjoys 24 water bodies designated as Ramsar international wetlands. The country has been facing dry conditions during recent years which has mounted ever-increasing pressure on these water bodies. This phenomenon along with land use/cover changes and various stakeholder groups that claim the right to use wetlands' water or their neighboring lands adds to the complexity of managing wetlands effectively. Unfortunately, boundary demarcation for nearly all of these 24 wetlands has been conducted solely using water extent and during the process the shrinking and expanding nature of water in dry and wet periods has often been ignored. Hence, although unofficially, issues have been raised between Iranian Department of the Environment as the organization in charge of wetland's protection and various stakeholders. Out of around 500 Persian papers and reports produced during the last decade in Iran (Magiran Website, 2014) focusing on relevant issues of wetlands, only two were found giving some hints about wetland boundary determination and none pointed directly to this topical issue. Luckily, with increasing availability of satellite remote sensing and other map sources and through field visits, it has now become possible to amend this neglected aspect of wetland protection. This research was designed as a pilot study for delineating the ecological wetland boundary in the international Alagol wetland of Iran for which no previous study on boundary determination was available. The research was also implemented to provide an example for future applications and pave the ground for similar studies.

2. Materials and methods

2.1. Study Area

The international Alagol wetland is the largest inland wetland in Golestan Province. This wetland is located between 37° 35' 00" (E) longitudes, and 37° 20' 00" (N) latitudes (Figure 1), and it is located in a dry climate, and its north and west sides are completely closed by embankments with a dam constructed on one of the wetland's outflows. The water level is very low in dry seasons and this problem is aggravated when water is extracted through the constructed dam for local use and nearby warm-water aquaculture. Soils are typically salty and poor; Lake Alagol is oligotrophic. It supports little aquatic vegetation except for some Juncus, Carex, and grasses, mainly in the north-east, and a few patches of reed beds, *Phragmites communis*. The lakes are utilized by a wide variety of waterfowl during the migration season and it is especially important in winterfor greater flamingo *Phoenicopterus ruber*, greylag goose *Anser anser*, dabbling ducks, pochard *Nettarufina*, smew *Mergellus albellus,* and coot *Fulica atra*. Breeding species include great crested grebe *Podiceps cristata*, black-winged stilt *Himantopus himantopus*, plover *Charadrius alexandrinus*, gull *Larus genei,* and *Remiz pendulinus*. Black stork *Ciconia nigra* has been recorded in summer and may breed (Information Sheet on Ramsar Wetlands, Lake Alagol).

2.2. Wetland Boundary Determination Plan

Determination of a wetland's boundary depends on distinguishing wetland from upland. The boundary was defined in transition between the wetland and upland. The identification of transition area was difficult on satellite images as also reported by Jackson (1995), so a field survey was undertaken during which points along transect were checked on a gradient from water towards upland.

To implement the process more accurately and to perform the sampling in wetland, a systematic survey of the wetland's environment is required. For this aim, transect sampling is normally recommended based on a systematic method. Transects should traverse the margin of the wetland travelling from the saturated zone (wettest or lowest lying area) to areas outside of the wetland. Sites along these transects should be chosen with reference to landform and vegetation changes (The Queensland Department of Natural Resources and Water, 2008). Therefore, nine transects each with a length of 1000 m (the primary length of each transect) were required while the length of some transects, increased or decreased according to topographical conditions. Survey of the area and information derived from satellite imagery, and field visits helped to define the sampling points on transects. Thus, sampling points at 0, 50, 100, 200, 400, 700 and 1000 m from the wetland area were considered and recorded by GPS based on satellite imagery, topographic maps, and survey of field conditions (Figure 1).

To determine the seasonal and temporary boundaries at each point, the soil indicators, plants, presence of fauna's nest, and other hydrological indicators were registered. Bird indicators helped determine ecological wetland boundary more completely.

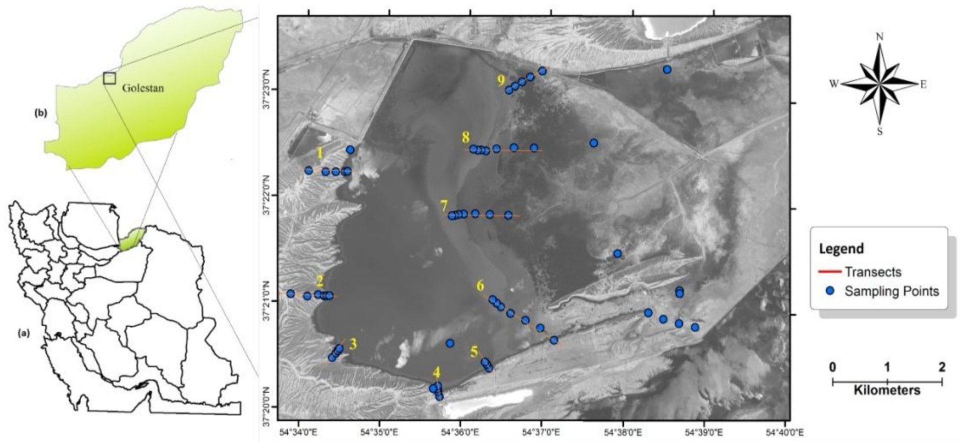

Figure 1. Location of the International Alagol wetland, a: Iran, b: Golestan Province; Transects and Sampling Points

2. 3. Topography

Wetlands usually occur in valleys; hence, terrain is normally an important practical indicator for identifying those parts of the landscape where wetlands are likely to occur (McVicar *et al.,* 1971). However, an area with soil wetness and/or vegetation indicators, but not any of the topographical indicators described above, should also not be excluded from being classified as a wetland (Department of Water Affairs and Forestry, 1999). In most wetlands with very low topographic features, the boundary determination is more difficult and complicated (Kusler, 2002). In Alagol wetland, due to the properties of the wetland's west and south terrain, and the dam dike in the north and northwest of the wetland, the topography indicators were useful and showed up on a 1:50,000-topography map. However, the eastern part of the wetland is completely flat, and topography was not useful in this direction. Therefore, we considered further field visits and other features.

2.4. Water Body Mapping

Satellite imagery helps change assessment and separating a wetland water area from other lands during dry and wet periods. Evaluating the maximum and minimum level of wetland water can be implemented using satellite imagery and

IDRISI Kilimanjaro (14.0.0.0). To separate the wetland basin, modified normalized difference water index (MNDWI[1]) can be used (Tiyip *et al.,* 2010). In this index, water features have positive values while soil and vegetation generally have negative values. We used multi-spectral Landsat 5 satellite images belonging to bands two and five of TM sensor for 19th of May 1986, 16th of September 1998, 25th of May 2000, 9th of August 2010, and 18th of July 2011. Using these data, the Alagol wetland area was separated from the periphery and was compared with field data. Finally, the maximum and minimum area of the wetland for flooded and drought situations were determined (Sefidan *et al.,* 2012). We found out that the wetland's water body was rather changeable during the year while the soil could be seen in gradients of moisture from totally saturated to those only wet in short periods.

2.5. Soil Sampling

Soils in wetlands are called hydric soils that are saturated, ponded, or flooded long enough during the growing season to cause anaerobic conditions in the upper horizons. Soil indicators are also usually the best for determining the areas that have been recently dried. Therefore, to determine the seasonal, permanent or temporary wetland areas, we first paid attention to the identification of hydric soils in certain areas.The changes in more soil features occur within 30 cm (12 inches) of the soil surface (Vasilas and Hurt, 2010). We sampled the soil profile 0-30 cm deep and studied properties such as soil texture, soil color as a sign of soil wetness and parameters of the electrical conductivity (EC) (Tiner, 1999). Additionally, we assessed percentage of mottles in the 30 cm of soil profile estimated in three levels, —less than 2%, 2-20%, and more than 20% (Richardson and Vepraskas, 2000). In this estimation, samples of the areas for which colored streaks were over 20% were determined as locating the boundaries of seasonal wetland and the areas with less than 20% colored spots in the soil samples were designated as temporary wetland areas.

2.6. Vegetation Sampling

For vegetation classification, we used Table 1. According to this table, plant species that almost grow in saturated or inundated conditions during the growing season (>99% of the time) are classified as obligate wetland species (OBL). Facultative wetland plants usually occur in wetlands (67-99% of the time), but are occasionally found in uplands (FACW). Facultative plants sometimes occur in wetlands (34-66% of the time), although they may be equally likely to occur in uplands (FAC). Facultative upland plants usually occur in uplands and are seldom found in wetlands (1-33% of the time) and are abbreviated as FACU. Plants that

1. MNDWI= (Green –MIR)/ (Green + MIR)

rarely occur in wetlands (i.e., have less than 1% probability of occurring in wetlands) are considered upland species, abbreviated as UPL (Tiner, 1991). Plants with indicator categories of OBL, FACW, or FAC that exhibit adaptations to life in saturated conditions can be considered wetland indicator plants (Jackson, 1995).

We conducted sampling in plots the size of which was determined based on vegetative layers. Plot locations were adjusted to ensure that the sampled vegetative layer was the representative of the plant community. The number of plots represented the complexity of the site. Circular plots with the following dimensions used: groundcover: 1-meter radius, shrubs: 5-meter radius, and trees: 9-meter radius (Jackson, 1995). Assessment began with the ground cover layer (when present).With the observation plots marked, plant abundance for each layer and species in the plot using percentage cover were evaluated. We first identified the plant species and the abundance of each was estimated. Dominance test was used to determine whether wetland indicative plants were dominant (meets or exceeds 50%) in number (Jackson, 1995). For this purpose, predominant plants were identified in sampling plots along with transects through coverage percentage calculation. According to the identified plant species and determination of wetland indicator types, we distinguished wetland and upland plant associations. In this way, the indicator category for each plant in Alagol Wetland was determined (Table 1). All plants in the indicator category of OBL, FACW, and FAC were defined as wetland indicator plants.

Table 1. Plant species list and wetland indicator plants status in Alagol Wetland (Iran)

No.	Species	Indicator Status
1	*Alhagi camelorum*	UPL
2	*Atriplex canescens*	UPL
3	*Artemisia herba-alba*	UPL
4	*Artemisia vulgaris*	UPL
5	*Aster altaicus*	FACW
6	*Chenopodium album*	FAC
7	*Chriospora toneiure*	UPL
8	*Erodium cicutarium*	UPL
9	*Euphorbia turkemanarum*	UPL
10	*Frankenia hirsuta*	FAC
11	*Halocnemum strobilaceum*	FACU
12	*Halostachy ssp*	FAC
13	*Juncus maritima*	FACW
14	*Kochia arenaria*	FAC
15	*Limonium reniformis*	FACW
16	*Limonium vulgare*	FACW
17	*Onosma sp*	UPL
18	*Phalaris minor*	UPL
19	*Phragmites australis*	OBL
20	*Plantago coronopus*	FAC
21	*Poa bulbosa*	UPL
22	*Rumex sp*	UPL

23	*Rhamnus pallasii*	UPL
24	*Salicornia herbacea*	FACW
25	*Salsola dendroides*	FAC
26	*Salsola orientalis*	UPL
27	*Suaeda maritima*	FAC
28	*Tamarix ramosissima*	FACW
29	*Tamarix gallica*	FACW
30	*Verbascum soongaricum*	UPL
31	*Peganum harmala*	UPL
32	*Cyperus longus*	FACW
33	*Myriophyllum spicatum*	OBL
34	*Aeluropus lagopoides*	UPL
35	*Aizon maritima*	UPL
36	*Zingeria sp*	UPL
37	*Capparis spinosa*	UPL
38	*Imperata cylindrica*	UPL
39	*Hordeum leporinum*	UPL

2.7. Fauna Assessment

The animal species with a lifespan dependent on wetland environments, and those with their life completely adjusted to wet conditions, are useful indicators for determining wetland habitats. Often information on the life cycle of fauna is required for the interpretation of wetland fauna indicators. In cases where large numbers of mobile fauna occur, such as colonies of breeding waterfowl, the abundance of fauna species associated with a particular vegetation community can identify a feature as a wetland area (Department of Environment and Resource Management, 2010).Thus, presence of waterfowl bird's nest was investigated near wetland boundary where the plants were also seen. Therefore, this index showed areas inside the boundary where got wet for at least some time during the year. The presence or absence of nesting birds and other animals like digger were registered along the maximum of circular plots (9-meter radius) for plants when the plants were being sampled. In addition, terrestrial and digger animals, and some reptiles helped in wetland boundary determination. The habitat of these animals is around wetlands, in places where the water table is usually low. Hence, presence of these animals' nests were registered and showed exterior areas of the wetland water boundary.

2.8. Ecological Wetland Boundary

The wetland ecological boundary was defined by considering three aspects of wetland ecological area, floodplain boundary, temporary boundary, and bird's flight radius (area sensitivity) maps.

In the Alagol wetland, due to the existence of hills in the west and south and dam dike in the north and northwest, topography indicators were useful. However, the east of the wetland is completely flat and so this indicator was not applicable. As such, we used plant indicators and wetland soils and birds in this direction.

These three indicators were studied by field samplingand also supported by interpretation of satellite images for plant coverage. Using this method, the seasonal and temporary boundaries of the wetland area were determined. To complement the ecological boundary, habitat of terrestrial animals and the flight radius of birds were considered in our case study.

The Environmental Law Institute's (2008) review of the science found that effective buffer sizes for wildlife protection may range from 10 and 1500 m depending on species and this area is from 50 m to more than 1500 m for birds, as the type and density of plant coverage is effective on home range of each animal. Nevertheless, type and density of buffer vegetation is useful for protecting particular species. Accordingly, the activity area of the birds was used as a focal type. By determining the Euclidean distance of the bird activity area, another boundary was also determined further away from the water body. The Euclidean distance from the temporary boundary up to the farthest points where the wetland dependent birds are generally active was calculated at 1000 m using ArcGIS software and Distance module.

2.9. Birds Flight Radius Mapping

Bird species are easy to study and normally a good representative of other fauna activity in every ecosystem. Therefore, in many studies, birds are chosen as focal species. Wetland dependent birds were recognized, then their flight radius (or area sensitivity) helped in determining the farthest line of ecological wetland boundary. According to birds' habitats (Jackson *et al*., 2004), bird area sensitivity (United States Natural Resources Conservation Service, 2007), and specialist knowledge, the recognized birds' flight radiuses were estimated in classes. The area of bird activities around wetland was divided into four classes (Table 2); class 1: less than 200 m, class 2: between 200 and 500 m, class 3: between 500 and 1000 m, and class 4: more than 1000 m. Most birds with a flight distance greater than 1000 meters were considered as the wetland's migratory birds and were eliminated from direct classification. The Euclidean distance of the bird activity area from temporary boundary was determined using topography map of the area.

Table 2. Birds flight radius (area sensitivity) classification

No.	Species	Birds flight radius classes
1	*Podiceps*	3
2	*Podiceps ruficollis*	3
3	*Podiceps auritus*	3
4	*Phalacrocorax carbo*	4
5	*Egretta alba*	4
6	*Aredea cinerea*	4
7	*Egretta garzetta*	4
8	*Anas platyrhynchos*	4

9	*Aythya farina*	4
10	*Anas acuta*	4
11	*Anas crecea*	4
12	*Anas strepera*	4
13	*Anas chypeata*	4
14	*Anas Penelope*	4
15	*Aythya futigula*	3
16	*Aythya marila*	3
17	*Aythya nyroca*	3
18	*Netta rufina*	3
19	*Fulica atra*	3
20	*Himantopus himantopus*	3
21	*Circus beruginosus*	4
22	*Limosa limosa*	4
23	*Platalea livcorodia*	4
24	*Oxyura leucocephala*	3
25	*Circus aeruginosus*	4
26	*Charadrinus dubius*	3
27	*Haliaeetus albicilla*	4
28	*Charadrinus alexndrinus*	3
29	*Charadrinus hiaticula*	3
30	*Sterna albifrons*	4
31	*Vanellus vanellus*	4
32	*Calidris alrina*	4
33	*Alcedo athis*	3
34	*Recurviosta avosetta*	4
35	*Larus minutes*	4
36	*Larus iohthaetus*	4
37	*Larus ridibundus*	4
38	*Larus genei*	4
39	*Larus argentatus*	4
40	*Tringa nebularia*	4
41	*Tringa ochropus*	3
42	*Tringa tetanus*	3
43	*Cygnus olar*	4
44	*Anser anser*	4
45	*Anser albifrons*	4
46	*Pelecanus cripus*	4
47	*Cygnus cygnus*	4
48	*Tadorna tadorna*	4
49	*Tadorna forruginea*	4
50	*Phoenicopterus ruber*	4
51	*Anser erythropus*	4
52	*Caldris minuta*	3
53	*Phalaropus lobatus*	3
54	*Sylvia sp*	2
55	*Galerida cristata*	2
56	*Coracias garrulous*	3
57	*Upupa epops*	3
58	*Motacila flava*	2
59	*Merops superciliosus*	4

3. Results and Discussion

3.1. Soil and Vegetation Results

The Results in Table 3, Figures 2 and 3 were reported for the first transect based on assessment of the soil, plants, and fauna nests along transects.

Table 3. Results of Soil, Plants, and Fauna Nests along the Transect 1

Transect 1		Points Number	01	02	03	04	05
		Distance from Coastline (meter)	0	50	100	200	400
		Elevation (meter)	-2.8	-0.9	4.1	13	9.7
		Slope (Degree)	1.5	2.7	6.2	4.1	4.3
	Soil Properties	Color	2.5GY 7/0 grayish white	2.5 Y 7/1 light gray	2.5 Y 8/2 light gray	2.5 Y 8/3 pale	2.5 Y 8/3 pale
		Mottles per cent	<2 %	2-20 %	0	0	0
		EC(mS/cm)	16.1	3.2	0.4	0.3	0.35
	Plant cover %	OBL & FACW	63	10	0	0	0
		FAC	23	23	2	0	0
		FACU & UPL	14	67	30	14	0
		Presence of Animals or Birds' nests	✓ (Bird's nest)	-	-	✓ (Diggers nest)	-
		Wetland area or not	Yes (Seasonal)	Yes (Temporary)	No	No	No

As can be seen, figure (2) shows cover percentage of wetland, transition, and upland vegetation along transect. Wetland vegetation cover was more than 50 percent at the beginning of transect near water, and in contrast, upland vegetation cover was less than 20 percent. The wetland cover percentage dropped dramatically along the transect one. Alternatively, the upland vegetation percentage reached rapidly a peak of more than 50 percent, thereafter dropped slowly to near zero in 400 m distance from the water. The point at 20 m distance along the transect one was where the two graphs met and showed the boundary point that is near the seasonal zone.

Figure 3 shows the estimated mottles changing and the distribution of the color of the soil matrix in 30-cm soil profile along the transect from wetland to upland indicating four zones in different lengths of time for wetness in the wetland. At the beginning of the transect, the abundance of mottles in the permanent zone near water was estimated about less than 2 percent.

The abundance of mottles rose sharply to a peak of more than 20 percent in the seasonal zone where distance of transect was 50 m. The graph line shows separating seasonal zones from 20 to 75 m distances from the water. Furthermore, this gradient decreased to less than 2 percent again in the temporary zone at a distance of 100 m from the water. However, mottles for the upland declined continually and dropped to zero.

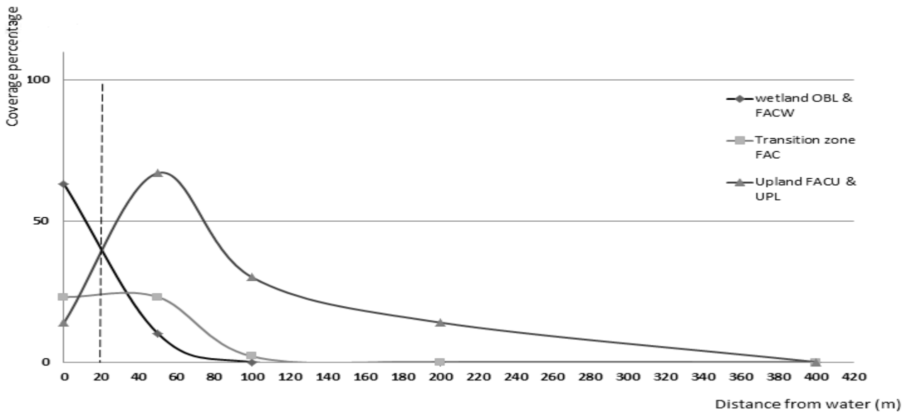

Figure 2. Diagram of the relative vegetation index based on wetland plants along a transect.

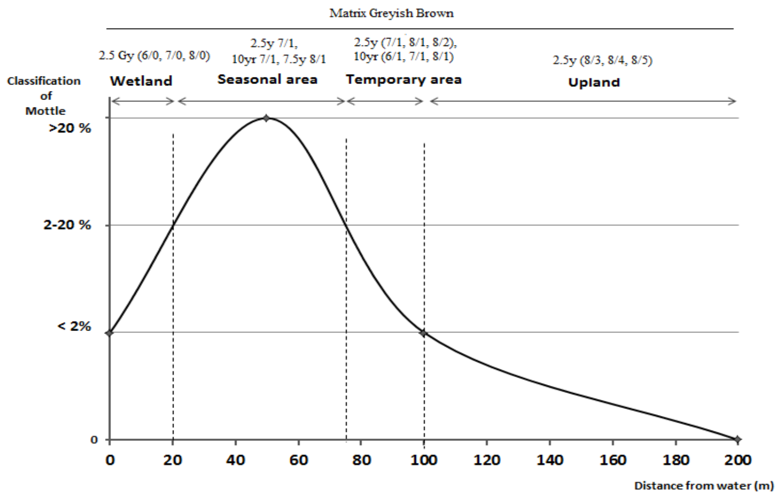

Figure 3. Diagram of mottles and color of the soil matrix in 30-cm soil profile along Transect 1.

To determine the marginal areas, the soil mottle percentage and plant indicators were used. Accordingly, the transition area was divided into seasonal and temporary areas. In most cases, the soil indicator was used to determine the seasonal and temporary boundaries, while the complementary results of plant indicators were also obtained. Wetland boundary line is presented in Table 4 according to plant indicators and soil using the distance from the first point of sampling on transects. In transects six, seven, and eight, which were located in east of the wetland, plant and soil indicators were still present even after the transect line reached the end and in such cases, the end line was determined using topography and plant classification map of the year 2011.

Table 4. Boundary points along each transect based on wetland plants and soils

Transects	Transition zone (meter)			
	Wetland indicator plants		Wetland indicator soils	
	Translation Vegetation	Boundary point	Seasonal Boundary point	Temporary Boundary point
1	10- 30	20	25	50
2	65 - 80	70	68	80
3	14- 24	19	15	30
4	50 -109	109	75	100
5	24 - 50	33	5	50
6	125- 1000	+1000	140	+1000
7	55 -1000	+1000	100	+1000
8	50-1000	+1000	100	+1000
9	0 - 400	400	350	450

Transition from wetland area to upland area is gradual and some wetlands have clear and sudden boundaries, so there is no need for detailed assessments of the establishment of the boundary. For example, topography in some wetlands sharply points to the wet conditions, but in other areas, the exact analysis of ecological indicators is necessary for boundary determination. After collecting environmental data, the final point with wetland soil in each transect and areas with wetland plants, and seasonal and temporary areas can be determined (Department of Environment and Resource Management, Australian Government, Department of the Environment and Heritage, 2010). Soil, vegetation, and topography are the main indicators of wetland areas for connecting the sampling points in each transect around the wetland to define the boundary. Changes in topography, in slope or differences in plant associations provide a good sign to connect the sampling points (Marnewecke *et al.,* 1999; Jackson, 1995). Therefore, using satellite images for preparing plant coverage map was very beneficial in this regard.

A map of the area was prepared in five classes using an un-supervised classification of Landsat TM images dated back to 18th of July 2011. By separating water, bare land, wet soil, and salt-water, three classes remained, which were identified based on predominant plants.

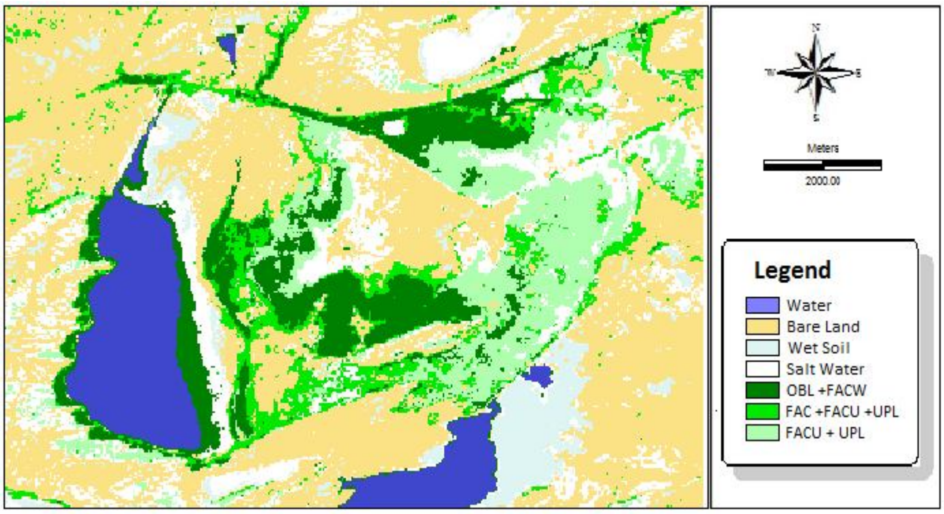

Figure 4. Alagol Wetland vegetation classification in 2011

Based on wetland plants index, Alagol vegetation map (Figure 4) was classified in three classes including (Overall accuracy: 82.5 and the Kappa: 0.78), 1.Wetland plants (OBL, FACW), with dominant plant including *Phragmites australis*, *Cyperus longus*, and Tamarixsp; 2. Facultative wetland plants (FAC, FACW) with dominant plants including *Halostachys sp*, *Alhagi camelorum*, *Aizon maritime,* and dried tamarix; 3.Optional upland plants and upland (UPL, FACU) with dominant plants including *Alhagi camelorum*, *Halocnemum strobilaceum* (Sefidian *et al.,* 2015).

In this way, the seasonal and temporary boundaries of the Alagol wetland were defined which can be seen in Figure 5. According to this figure, the seasonal area of Alagol wetland is 1464.19 hectares and its temporary area is 2384.72 hectares.

3.2. Water body Boundaries

As it is shown in Figure 5, using MNDWI index, the results indicate that the water boundary in 1998 (the highest rate of flooding) was set as the wetland flooded boundary and the water boundary in 2011 (the lowest rate of flooding) was set as the wetland permanent boundary (Sefidian *et al.,* 2012).

3.3. Ecological wetland boundary

Using the Euclidean distance of the bird activity area, and other information, the ecological boundary of the Alagol wetland was determined which is displayed in Figure 5. As such, the area of the wetland reaches 3899.69 hectares.

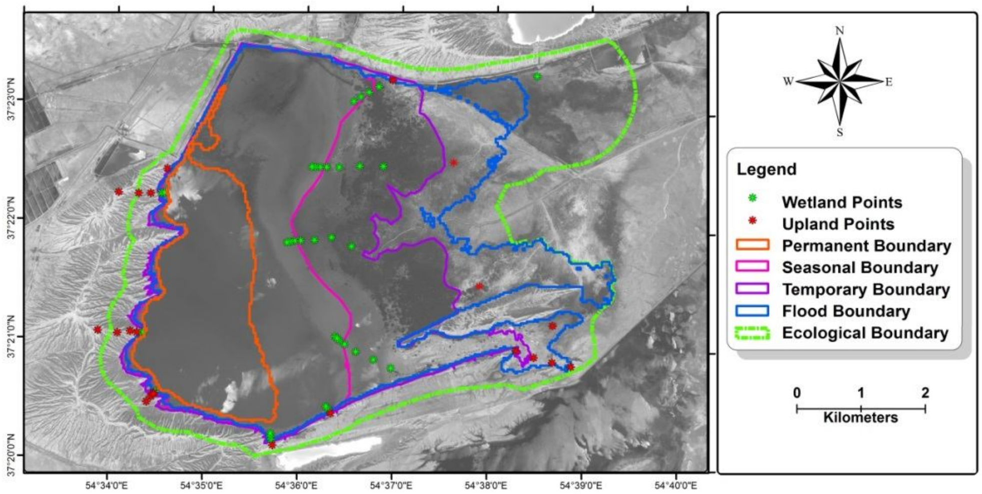

Figure 5. Wetland and upland points, seasonal, temporary, and ecological boundary of the International Alagol wetland

Studying plants, soil and hydrological conditions around the wetland showed a process of changes in temporary flooding limits. Based on the results in transects 1 to 5, the distribution of plant communities is affected by terrain that has an increasing slope. The wetland plant communities such as Tamaricaceae (*Tamarix ramosissima* or *Tamarix gallica*) and *Phragmites australis* are distributed like a narrow band around the wetland. In these areas, the wetland plants reduce along transects and upland plants increase which include mostly *Alhagi cameleron* and/or *Artemisia vulgaris*. With increasing slope, the EC decreases and soil texture changes to loamy sand in the foothills; the existence of nests of rodents such as *Rhombomys opimus* indicates that the water level is low and it can be concluded that wetland water does not usually reach these areas. Hence, in the areas the difference between wetland seasonal and temporary boundary is negligible, and ranges from 20 to 150 m, although in transect 5 there are walls at the south edge of the wetland which create a barrier to wetland water development.

Transects 6 to 8, on the eastern side of the wetland, represent the areas with seasonal and temporary flooded zones. In these transects, wetland plants such as *Salicornia herbacea* and Tamaricaceae (*Tamarix ramosissima* or *Tamarix gallica*) are reduced in number, and stable upland plants such as *Halocnemum strobilaceum* increase in number to the point that they reach a balance and the percent coverage of both types slides gradually. Reduction of wetland plants is caused by low soil moisture, and reduction of upland plants is caused by high soil salinity (more than 15 ms/cm); high salinity can indicate past flood in these areas.

Hydric soils can be divided into two groups of organic soils and hydric mineral soils (and oxidized rhizospheres) in the field using soil test holes. The color of soil components are often the most effective diagnostic indicator of hydromorphic soils. The frequency and duration of soil saturation strongly influences the colors of these components. Generally, the higher the duration and frequency of saturation in a soil profile, the more prominent the grey colors become in the soil matrix (Tiner, 1999). Mottles and other features of hydromorphic soils are usually absent in permanently saturated soils, and are prominent in seasonally saturated soils becoming less abundant in temporarily saturated soils to the point that they disappear altogether in dry soils. Generally, in mineral soils, a grey soil matrix and/or mottles must be present for the soil horizon to qualify as having signs of wetness in the temporary, seasonal, and permanent zones (Richardson and Vepraskas, 2000).

The increase in the percentage of mottles in 30 cm of soil profile shows that these areas are seasonal (Richardson and Vepraskas, 2000). At the end of transects 6 to 8, we reach a large dried Tamaricaceae population across a large area that might be an evidence of temporary inundation in past years a reduction in the percentage of mottles in 30 cm of the soil profile emphasizes the temporary inundation (Marnewecke *et al.,*1999). Getting closer to the exit channel in the west of the wetland, the input of wetland water increases the Tamaricaceae community after which upland stable plants (UPL) around the channel area have good growth (types of Salsolaceae) and soil is void of mottles, its moisture is low, EC is medium, and pH is neutral and there are no indicators of wetland. According to the estimated flooded boundary from satellite images, these areas are part of the wetland-flooded area. In these areas, the difference between the seasonal and temporary wetland boundary is higher than other parts of the wetland and it usually varies from 900 to 2000 m.

Transect 9 in the northwest of the wetland begins from the water area. Soil in this location has clay and surface soil cracks with lots of mottles; EC is 18/3 ms/cm and has no plants. This can be a result of this location serving as a basin in the high wet seasons (U.S. Army Engineer Research and Development Center, 2008). Gradually the straw population increases until most of the Tamaricaceae population and *Juncus maritima* replace *Phragmites australis*, but signs of wetland soil gradually decrease until the EC reaches 1.44 ms/cm. The transect ends at the dam dike in the north edge of the wetland. Upland soils at the end of transect, and OBL plants show temporary inundation towards the dam dike. The plant and soil identification standards used to identify wetland and upland areas in the study sites have been summarized in Table 5.

3.4. The Indicators used for Identification of the Ecological Boundary

Determination of the ecological boundary of wetland is a necessary tool for choosing and managing protected wetland areas. Therefore, it is important to specify the ecological boundary of the wetland for its legal protection. The ecological boundary is an area beyond the maximum body of water, and covers the habitat of the wetland dependent/loving animals as well. Study of hydrology, soil, and plants is necessary for proper determination of the wetland boundary (Laliberte *et al.,* 2007). However, determination of the dependent wildlife can complete this process. In this respect, birds as focal species that require protection in the wetland boundary provide a good surrogate. In the present research, in addition to visiting the area and using wetland surveys, the maximum flight range of the wetland dependent/loving birds was used as an indicator. Due to their representativeness, birds can be used as focal types.

Table 5. Criteria for distinguishing different soil and vegetation zones within wetland

Wetland Zones	Permanent	Seasonal	Temporary	Upland
Soil depth (0-30 cm)	Saturated Soil	High Water Table (Surface Soil Cracks)	Usually Dried Soil	Dried Soil
	Matrix Greyish Brown 2.5 Gy (6/0, 7/0, 8/0)	Matrix Greyish Brown 2.5y 7/1, 10yr 7/1, 7.5y 8/1	Matrix Greyish Brown 2.5y (7/1, 8/1, 8/2), 10yr (6/1, 7/1, 8/1)	Matrix Greyish Brown 2.5y (8/3, 8/4, 8/5)
	No/Few Mottles; <2 % Motels	Many Mottles; >20 % Motels	Few/Many Mottles; 2-20 % Motels	No/Few Mottles; <2 % Motels
	EC >18 mS/cm	EC 5-18 mS/cm	EC 8-18 mS/cm	EC <18 mS/cm
Dominant Plants	Wetl nd Plants 20-50 % or >50 % *Phragmites australis* *Tamarix ramsissima* *Tamarix galica*	Wetland Plants 5-20 % *Tamarix ramsissima* *Tamarix galica* *Salicornia herbacea* *Limonium vulgaris*	Upland Plants 20-50 % *Halocnemum strobilaceum* *Halostachys spp* *Artemisia vulgaris*	Upland Plants >50 % *Halocnemum strobilaceum* *Alhagicameleron* *Aizon maritime* *Peganum harmala*

A dam dike in the north and northwest of the wetland caused the ecological boundary to rise up to 200 meters. In the south and west sides of the wetland, for reasons of topography and the low density of plant coverage, animal indicators were determined up to 500 meters from the water body margin. Since plant coverage is vast at the east of the wetland, the variety and density of birds including aquatic, semi-aquatic, and terrestrial is higher. Coraciiformes, Pteroclidiformes, Columbiformes, Passeriformes, and Falconiformes are marginal terrestrial birds of this wetland, and can be found residing, visiting, and spawning around the wetland or inside the shrubs and reeds (Kiabi *et al.,* 1999).

Therefore, 1000 m of the land from the temporary margin—including the flooded margin of the wetland—was considered as the ecological margin so that the nests of these birds can be protected as focal types in the wetland's boundary. Protecting terrestrial birds dependent on wetland with an activity radius more than 1000 meters (such as Falconiformes) is both possible and necessary which can be realized in a buffer zone further from the ecological boundary.

4. Conclusion

The results of our study revealed that water extent alone could not represent wetland boundary. Hence, to determine this boundary properly, we included animals and especially birds in addition to the normal protocol that considers ecological features such as hydrology, vegetation, and soils to complete the process. In this study, ecological wetland boundary was determined using hydrology, plant species, and birds active within a 1000 m radius of the initial water body of the Alagol wetland. This ensured integration of the birds' nests as biodiversity indicators within the wetland's boundary and their proper protection. Protection of other wetland birds in areas further than 1000 m from the initial boundary was also considered in the suggested buffer of the wetland. The whole process is suggested for boundary determination of other 23 international wetlands designated as Ramsar sites in Iran. The result of this research helps better negotiation with neighboring communities and settles conflicts with stakeholders towards a more sustainable wetland management.

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