Трансформация экосистем
Ecosystem Transformation
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The use of modern and archive remote sensing data for GIS monitoring of riparian ecosystems

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Received: 09.02.2018
Accepted: 26.03.2018
Published online: 08.05.2018

DOI: 10.23859/estr-180209
UDC 87.35.02:89.57.45
URL: http://www.ecosysttrans.com/publikatsii/detail_page.php?ID=67

ISSN 2619-094X Print
ISSN 2619-0931 Online

Translated by S.V. Nikolaeva

Association of lowland reservoirs with marsh systems at an ordinary water level amplitude of 3–5 m can increase the total flooding area 1.5–2 times. The use of remote sensing and GIS for the processing and storage of satellite and field data allows the study and monitoring of wetland ecosystems at a new information and cartographic level, as well as correcting and supplementing existing literary and cartographic data. In this work we used ERS data obtained from the modern Landsat-8 and Sentinel-2 satellites. The GIS-based analysis of changes in the studied landscapes revealed the zone of direct influence of the reservoir inland up to 3.5 km, and allowed the areas of shallow water and adjacent wetland ecosystems to be evaluated and four hydrological zones to be established.

Key words: ecotone, marsh ecosystems, reservoir, basin, floodplain, flooded areas, satellite imagery.

Kutuzov, A.V., 2018. The use of modern and archive remote sensing data for GIS monitoring of riparian ecosystems. *Ecosystem Transformation* **1** (1), 24–28.

Introduction

Large marsh systems are often associated with large-scale water objects: lowland lakes and reservoirs (Lake Peipius, Ladoga, Rybinsk Reservoir and others). A number of lakes have a drain regulated by a dam, and so are partially converted into natural reservoirs (for example: Vygozero, Lake Onega). The direct interaction of such basins with marsh systems, when the water level rises, is carried out in two ways:

– through direct flooding of wetlands and swales, including the overtopping of river channels;

– through a significant slowdown of surface and groundwater infiltration aggravating floods.

Fluctuations in the water level should have a significant impact on associated marsh ecosystems, and the greater the range of water level fluctuations, the greater its contribution to the dynamics of wetland areas. On a plain, even small (1–2 m) fluctuations in the water level can cause flooding (or drainage) of vast land areas, whereas a periodic differential of 3–5 m may result in a twofold change in the area of the entire reservoir. For the Rybinsk Reservoir such a change in the flooded area may be more than 2000 km^2 (Avakyan and Voropaev, 1986). Even a slight decrease in the level by 0.4 m from a typical maximum (in this case the maximum static full pool, or SFP, 101.81 m BVD – Baltic vertical datum) leads to a 4% decrease in the flooded land area, based on the analysis of satellite imagery – remote sensing data, RS (Kutuzov, 2011b).

The last decades saw the formation of wetlands on the shallow areas of the Rybinsk Reservoir. With significant drying of shallow areas of the littoral zone, in years with extremely low water levels, land hydrophilic vegetation colonizes new shoreline habitats.

Pioneering vegetation types include reeds, common-club rush, and willow shrubs (Poddubniy et al., 2017; Zakonnov and Lyashenko, 2004). Due to the continuous dynamics of the coasts, it is especially important to study wetland areas near the Rybinsk Reservoir using satellite images.

Modern approaches to the hydrobiological study of marshes and their surface hydrographic network suggest the use of a whole range of methods for monitoring the territory (Filippov et al., 2017). The systematic use of remote sensing and the use of geographic information systems (GIS) for the processing and storage of satellite and field data allow the study and monitoring of wetland ecosystems at a new information and cartographic level, in digital form and vector graphics. This comprehensive approach allows available literary and cartographic data to be amended and updated, including the extent and distribution of wetlands in the study area, and determining the types of vegetation and zoning of hard-to-reach areas (Filonenko and Philippov, 2013).

Currently, the analysis of changes in landscapes and modelling of their structure can be effectively carried out using GIS-technologies, which provides unification of digital data formats, automation and high speed data feeds in databases (DB), as well as visualization and layout of process dynamics. However, automated processing of field materials requires preliminary work on their translation into an electronic database and inclusion in GIS.

Material and methods

In this work, valuable remote sensing data was obtained from the Landsat-8 (15–30 m/pixel) and Sentinel-2 (10 m/pixel) satellites. The analysis of remote sensing data of multispectral survey contours of marshes and surface waters are to be determined for different reservoir level by selecting a combination of display of channels in the visible and infrared ranges (Kutuzov, 2011a). The automatically obtained contours were processed for four isolated shallow-water areas of the Rybinsk Reservoir, located on two contrasting types of coasts: with steep and gently rising banks, respectively (Table 1). GIS mapping results were obtained for Radovsky Island (length about 3.1 km, area, with internal basins, about 1.8 km^2) and adjacent regions (Fig. 1). Calculations were made of flooded areas for isolated shallow-water zones of Radovsky Island and the Tryasie Islands. For fieldwork, we used satellite navigators (and other mobile devices) with loaded maps and satellite layers; these navigation materials,

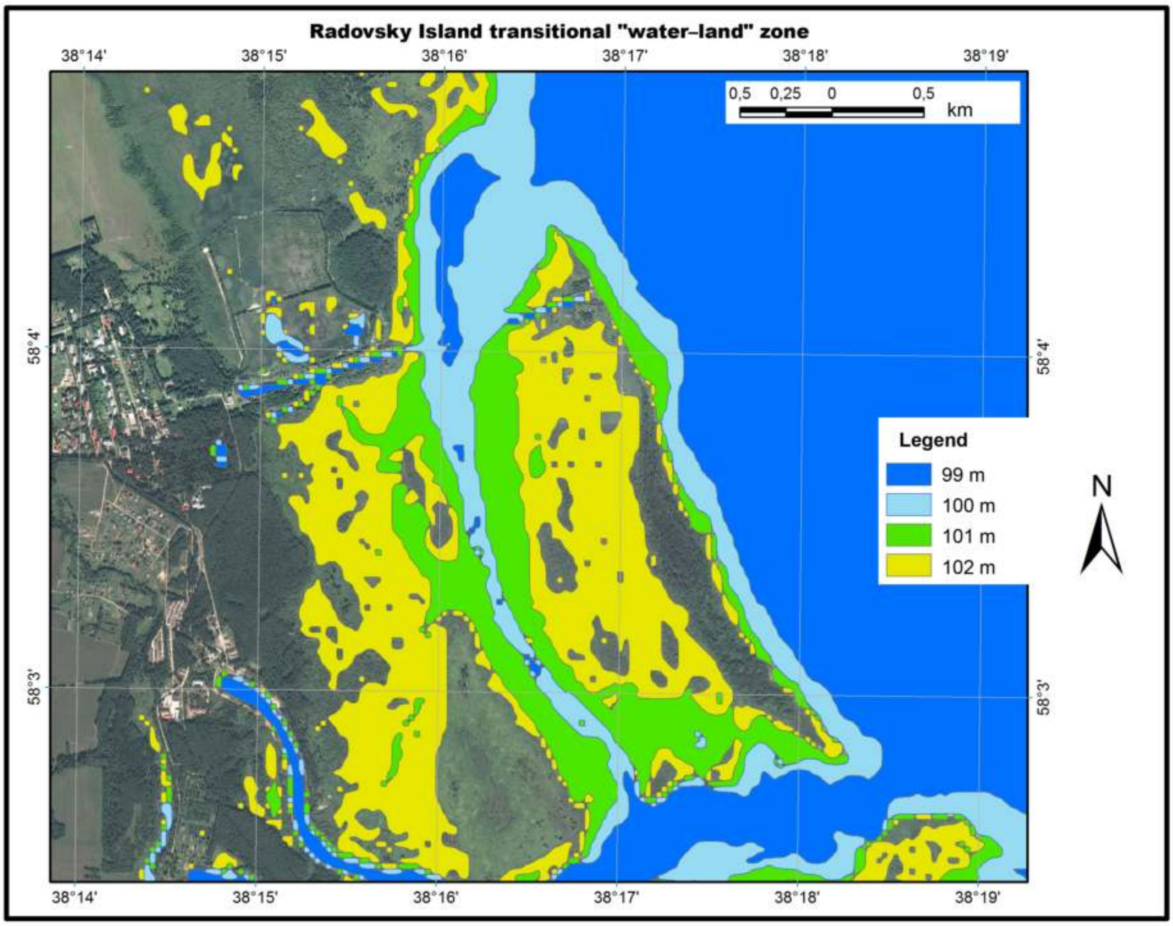

Figure 1. Radovsky Island, Rybinsk Reservoir, transitional "water–land" zone.

coordinates of survey points and their descriptions were subsequently processed in desktop GIS.

The use of remote sensing archive data (for Landsat, individual images have been available since the 1970s) provide the possibility of analyzing the long-term dynamics of wetland areas. This study summarizes the results of GIS (QGIS 2.8 and ArcMap 10.0) processing of ERS data for 2013–2016.

The boundaries of wetland areas and the marsh systems change throughout time, under the influence of both natural and human impacts. It is necessary to distinguish between regular (seasonal, annual) and extreme fluctuations in the level affecting associated ecosystems of marshes and shoals (Table 1, extremes 99 m and 102 m). The table below shows the results of automatic calculations, the accuracy of which depends on the accuracy of the remote sensing data – the spatial resolution of the satellite image (in our data: 10–30 m/pixel).

Recognition and vectorization of various types of objects in the studied area was based on differences in the spectral brightness of the sections for each optical range. Thus, at the reservoir level close to the maximum values, near the SFP (101.81 m BVD), most of the wetlands are flooded with surface waters. In the infrared range of optical photography, open water intensively absorbs sunlight and looks dark (the spectral brightness is minimal), which is readily recognized in photographs at the beginning of the growing season and is masked later by emergent macrophytes (common reed and common club-rush) growing in shallow waters (Fig. 1).

Large basins adjacent to the marsh ecosystems form a special transitional (ecotonic) zone of interaction of different ecosystems. A specific biota with a wide ecological valence to hydrological conditions is formed here. The scale of such an ecotone belt of interfacing ecosystems can be measured in kilometers for gently sloping coasts (in our studies: up to 3.5 km) or be practically absent for steep banks and cliffs. The definition of the ecosystem boundaries enables typologization of patchy areas by making it possible to identify individual typical survey sites (reference or key areas), facilitating the assessment of the full resource potential for the entire reservoir. The number of basic types of territories in the ecotone zone is taken to be four, depending on the hydrological regime – in accordance with four main ground blocks of the "water–land" ecotone system: fluctuational, dynamic, distant and marginal blocks (Balyuk et al., 2007; Zaletayev, 1997).

Results and discussion

The analysis of the obtained data makes it possible to estimate the level ranges of the Rybinsk Reservoir, which form the blocks of the "water–land" ecotone system. For instance, the fluctuation type (different periodicity of flooding) of the "water–land" ecotone zones on the coast of the Rybinsk Reservoir includes the level range 99–101 m (Fig. 1), the dynamic type includes the range of 101–102 m. Above (Fig. 1) there is a distant block, represented mainly by forests; the marginal block is beyond the limits of this map.

A digital 3D model of the coastlines of Radovsky Island and adjacent areas was obtained in the GIS project and four typical zones of hydrological impact are substantiated in accordance with four ground blocks of the "water–land" ecotone. In the course of the work water levels (extreme: 99 m and 102 m) and regular (100 m and 101 m) critical of the vegetation period for the Rybinsk Reservoir (Fig. 1) were determined, which determine the dynamics of the shoreline communities.

The level regime of the Rybinsk Reservoir (regular and extreme level fluctuations) has a formative effect on the entire coast in general and on the "water-land" ecotone system. Sharp significant changes or long trends, which differ from typical seasonal water level variations, change the suitable environment and boundaries of associated wetlands. Table 1 presents examples of the results of calculation of flooded areas for two surveyed areas of the coastal zone: gentle rise (Radovsky Island) – smooth, uniform increase in flooded area; steep ascent and shore bank (Tryasye Islands) – a sharp increase in the area of flooding at a high water level, overtopping.

The results of our RS data analysis are promising for the quantitative assessment of specific natural resources, and the identification of interesting

Interval, m	Total S for Radovsky Island, km^2	Total S for Tryasye Islands, km^2
below 99	0.423	0.189
99–100	2.076	1.099
100–101	4.259	2.496
101–102	6.598	5.357

Table 1. The areas of the two contrasting flooded areas of the coastal strip: isolated shallow-water areas and wetlands associated with the Rybinsk Reservoir (based on the results of the GIS processing of remote sensing data for 2013–2016).

objects in various territories. For other purposes, including for the quantification of natural resources, particular methods of the typology of the territory can be developed to identify the objects of interest. This can be used to assess the potential for recreation, sports and hunting, fishing, forestry, marsh and agricultural resources, as well as social infrastructure. For example, the determination of the optimal level regime of the reservoir is of importance for the fishing industry – a high level during spawning and growth of fish fry in shallow water provides a many-fold increase in the survival rate of juvenile fish (Stolbunov, 2016).

For normal reproduction, many species of fish need shallow spawning grounds with an herbaceous plant substrate, for eggs to be laid on. Such spawning grounds are usually formed in the floodplain zone; flooding occurs very irregularly, so that at low flood levels the spawning areas are sharply reduced. At the same time, spawning and high survival of eggs require stability of the water level and duration of flooding, which are provided by a sufficiently high level of the reservoir. Thus, the accuracy of determination of the distribution potential and the area of these lands enable a justified forecast of the influence of level variations on the quantity of young fish. Such calculations, taking into account the typology of the territory, are the basis for a reasonable assessment of the economic effect: both from industrial fishing, and from increasing the recreational attractiveness of a reservoir (for example, sport fishing and other types of outdoor activities).

Conclusions

In the course of this study, the whole territory of the coast of the Rybinsk Reservoir was mapped based on remote sensing data: Sentinel-2 and Landsat-8 (spatial resolution 10–30 m/pixel). For the four model territories, two key areas were identified, where automatically generated contours were computed using GIS (Fig. 1) and flood areas were calculated in the 3D model of the coast, at different levels of the reservoir level (Table 1).The analysis of the changes in the landscapes studied using GIS technologies showed the range of a direct inland influence of the reservoir (in this study up to 3.5 km) and made it possible to determine the areas of shallow water and adjacent wetland ecosystems.

The data obtained allow the study and monitoring of wetland ecosystems at a new information and cartographic level (DB, vector maps), as well as correcting and supplementing existing literary and cartographic data, zoning hard-to-reach areas, and allowing very accurate estimations of the surveyed areas (within 100 m^2). In the future, methods can be developed for more detailed typology of territories: an estimation of recreational, hunting and commercial, forest, marsh and agricultural resources.

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