Pol. J. Environ. Stud. Vol. 23, No. 2 (2014), 639-645

Short Communication

Application of GIS and GPS Tools in Qualification and Classification of a Lake's Ecological Status

Piotr Dynowski[1], Anna Źróbek-Sokolnik[1]*, Hanna Ciecierska[1], Jan Dziedzic[1], Ryszard Piotrowicz[2], Czesław Hołdyński[1]

[1]Department of Botany and Nature Protection, University of Warmia and Mazury in Olsztyn, Plac Łódzki 1, 10-719 Olsztyn, Poland
[2]Institute of Environmental Biology, Adam Mickiewicz University in Poznań, Umultowska 89, 61-701 Poznań, Poland

Received: 26 September 2013
Accepted: 14 January 2014

Abstract

The use of simple GIS and GPS techniques as tools supporting field data collection in the process of macrophyte-based assessment and classification of the ecological status of lakes is described in the paper. The ecological status of Lake Długie was determined with traditional water quality evaluation methods, including the "anchor" or "diving and GIS" method. Obtained results show simple GIS techniques for registering submerged plant communities supplemented with terrain investigations involving scuba diving, producing more accurate data than those acquired with traditional methods.

Keywords: ecological state macrophyte index, EU Water Framework Directive, GIS, GPS, mapping

Introduction

In line with the requirements of the EU Water Framework Directive [1], the ecological status of aquatic ecosystems should be assessed based on biological elements (phytoplankton, phytobenthos, zoobenthos, fish, and macrophytes) that replaced the physicochemical properties of water in the evaluation scheme. In the current classification system, the ecological status of an aquatic ecosystem is assessed based on an individual evaluation of each biological indicator, followed by an integrated approach. All EU Member States have to develop methods for the above assessment, involving different biological parameters, with respect to different types of water bodies (lakes, rivers, dams, and other), and abiotic factors within each water body type.

This paper compares the accuracy of traditional methods of surveying submerged vegetation with mapping techniques that involve underwater exploration, geographic information systems (GIS), and satellite positioning. The applied techniques support detailed evaluations of the distribution and environmental status of macrophyte communities, including the vulnerable species *Isoëtes lacustris*. Lake quillwort is subject to strict protection [2]. It is listed as a vulnerable species (VU) in the Polish Red Data Book of Plants [3] and the Red list of plants and fungi in Poland [4]. The resulting information provides highly valuable inputs for monitoring projects.

*e-mail: a.zrobeksokolnik@uwm.edu.pl

Study Area

In 2012 data on the occurrence and distribution of macrophyte communities in Lake Długie were collected by different methods. The lake is located in northeastern Poland (N 53º49'5" and E 20º1'23"), at an altitude of 101.8 m a.s.l. Lake Długie has a strongly elongated shape from the northwest to the southeast, and it features seven bays (Fig. 1).

Morphometry of the lake is presented in Table 1. Lake Długie is a hydrologically open water body. A seasonal water course connects this water body to Lake Gil in its

Table 1. Morphometry of Lake Długie.

Lake area (ha)	82.83-89.9 [7-9]
Maximum depth (m)	18
Average depth (m)	6
Maximum length (m)	3,500
Maximum width (m)	450
Shoreline length (m)	9,500

northwestern part and to Lake Harcerskie in its south-central section. The analyzed lake has been included within the boundaries of the Lake Długie reserve [5], the Natura 2000 network of protected areas (PLH280030 Lake Długie), and the Protected Landscape Area of the Taborski Forest Complex [6], due to the presence of *Isoëtes lacustris* locations.

Methods

Research Methods Applied before Field Surveys

Prior to conducting field investigations in the study area, the number of transects to be surveyed was determined. The transects were plotted on a bathymetric map, including the full range of local conditions in the lake, catchment management, and shoreline development (bays, islands, inlets, outlets, etc.). The number of transects was calculated using the formula proposed by Jensen [10].

Fieldwork Methods

The vegetation in Lake Długie was analyzed with the use of the transect-based Ecological State Macrophyte Index (ESMI_trans) method, recommended in the EU Water Framework Directive [1], developed in 2006 for Polish environmental protection services [11, 12]. Surveys were carried out along belt transects (min. 30 m in width). The maximum depth of plant colonization and the percentage cover of vegetation were determined, and all plant communities were listed, determining the share of each community on a 7-point scale proposed by Braun-Blanquet [13]. Investigations were preceeded by:

(1) dredging bottom of the lake with an anchor (“anchor method”) or
(2) underwater investigations proceeded by divers and a team working on the boat (“diving and GIS method”).

In both cases, the transects were positioned based on geographic coordinates recorded with a GPS receiver (Fig. 2). We recommend marking the start and end points of transect lines for monitoring purposes in all EU member states.

The boundaries of plant communities were recorded as sets of points with known geographic coordinates, which could be further processed in the GIS (Fig. 3). The surface area limited by the 2.5 m isobath also was determined.

Fig. 1. Location and shape of Lake Długie with *Isoëtes lacustris* positions
Source: Own study

Study Methods – Determination of Indicators to Assess the Ecological Status of Lakes

Irrespective of the research methods deployed, the ecological status of water bodies is evaluated in the field based on the same indicators, in accordance with the ESMI method [11, 14]. The only difference is in determining the absolute surface areas of plant communities and the phytolittoral zone. In the "anchor method" (1), the grades of the Braun-Blanquet scale [13] are converted to the corresponding cover classes introduced for Polish lakes [14] (Table 2). In the "diving and GIS method" (2), the surface areas of plant communities are calculated based on satellite positioning with the use of GIS tools.

The ESMI method relies on the ESMI (ecological state macrophyte index) multi-metric index (Table 3) and other qualitative (S – number of plant communities, H – phytocenotic diversity index, H_{max} – index of the theoretical maximum phytocenotic diversity) and quantitative (N – phytolittoral surface area, Z – colonization index, surface areas of different ecological groups: charophytes) indicators.

$$ESMI = 1 - \exp\left[-\frac{H}{H_{\max}} \times Z \times \exp\left(\frac{N}{P} \right) \right]$$

The surface area limited by the 2.5 isobath, required for further computations, may be determined using bathymetric data collected in the 1950s and 1960s in Poland (however, in many cases the data are outdated). Using an echosounder and a GPS receiver, and checking many coordinates for a depth of 2.5 m, such an isobath can be determined with high accuracy, in the form of a polygon whose area can be computed automatically with GIS tools.

Table 2. Average vegetation cover (Braun-Blanquet's scale).

Ranges of cover classes	Braun-Blanquet's class	Cover means (%)
75-100	5	86
50-75	4	61
25-50	3	34
2-25	2	15
1-5	1	3
0.1-1	+	0.5
< 0.1	r	0.1

Table 3. Ranges of ESMI values for particular lake types and ecological status classes.

Ecological status	Ranges of ESMI values	
	Deep charophyte-colonized lakes	Shallow charophyte-colonized lakes
High (very good)	0.680-1.000	0.680-1.000
Good	0.410-0.697	0.270-0.679
Moderate	0.170-0.400	0.110-0.269
Poor	0.090-0.169	0.050-0.109
Bad	<0.090	<0.050
	no submerged vegetation	

Source: Regulation of Council of Ministers 2013 – project

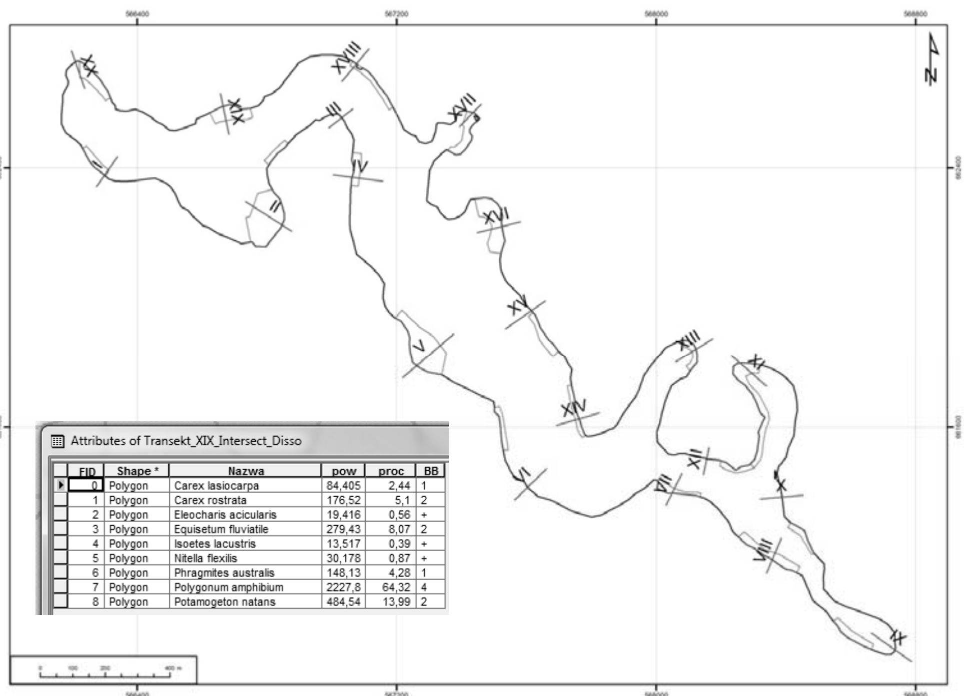

Fig. 2. Locations of belt transects and a sample table of communities taking into account the percentage of coverage of the transect through the communities of assigned Braun-Blanquet's scale with GIS.
Source: Own study.

Results

Lake Długie is a deep charophyte-colonized lake. A total of 25 plant communities were identified in the study. The number of communities determined by the anchor method was 23, while the diving and GIS method determined 25 communities (Table 4). Additionally, using the second method allowed us to identify *Isoëtes lacustris* communities (Fig. 1) that were not found when the previous methods were employed. These communities occupied a relatively large area of the bottom and are of great importance for this water body.

The area of the phytolittoral zone was estimated differently in each of the methods, which is why the values of the applied indicators vary insignificantly (Table 5). Due to the larger number of community distinction (S) using the method of GIS transects, higher values were obtained in both phytocenotic diversity index (H) and the maximum version (H_{max}). In the case of GIS, methods obtained lower surfaces phytolittoral (N) and lower values of the settlement (Z) (Table 5).

It was assigned to each transect attribute table in which one of the columns automatically calculates the surface of the bottom coated by a particular community on the transect and the column with an assigned value in the scale of Braun-Blanquet (Fig. 2). In spite of setting the same value of the average maximum depth of plant colonization (C_{max}) – both methods were estimated of significantly less vegetation cover bottom (using GIS), which decreased the value of the indicator ESMI.

The assessment of the ecological status of Lake Długie can be set at a level of good (the anchor method) or good/moderate (the diving and GIS method).

Discussion

The application of GIS to the field of aquatic botany and also to modeling of submerged macrophyte distribution has been more and more often proposed as a good method that has been warranted for over a decade [15-18].

As we noted in our previous article [19], the most popular method used for a lake's submergered plant registration is dredging the lake bottom with an anchor. This method is also used during lake valuation and ecological status classification according to macrophyte-base assessment [14, 20], and it is permissible within EU Water Framework Directive requirements. However, this method is very subjective and interferes with the environment. And in the case of throwing low frequency it is burdened with high error. This error is connected with not taking into account worthwhile species occupying smaller areas or occurring in communities creating gradient disposition. We suggested that the combination of underwater inventories analyzing bottom strata saturated with light, satellite positioning, and GIS tools produces the most reliable results [19, 21].

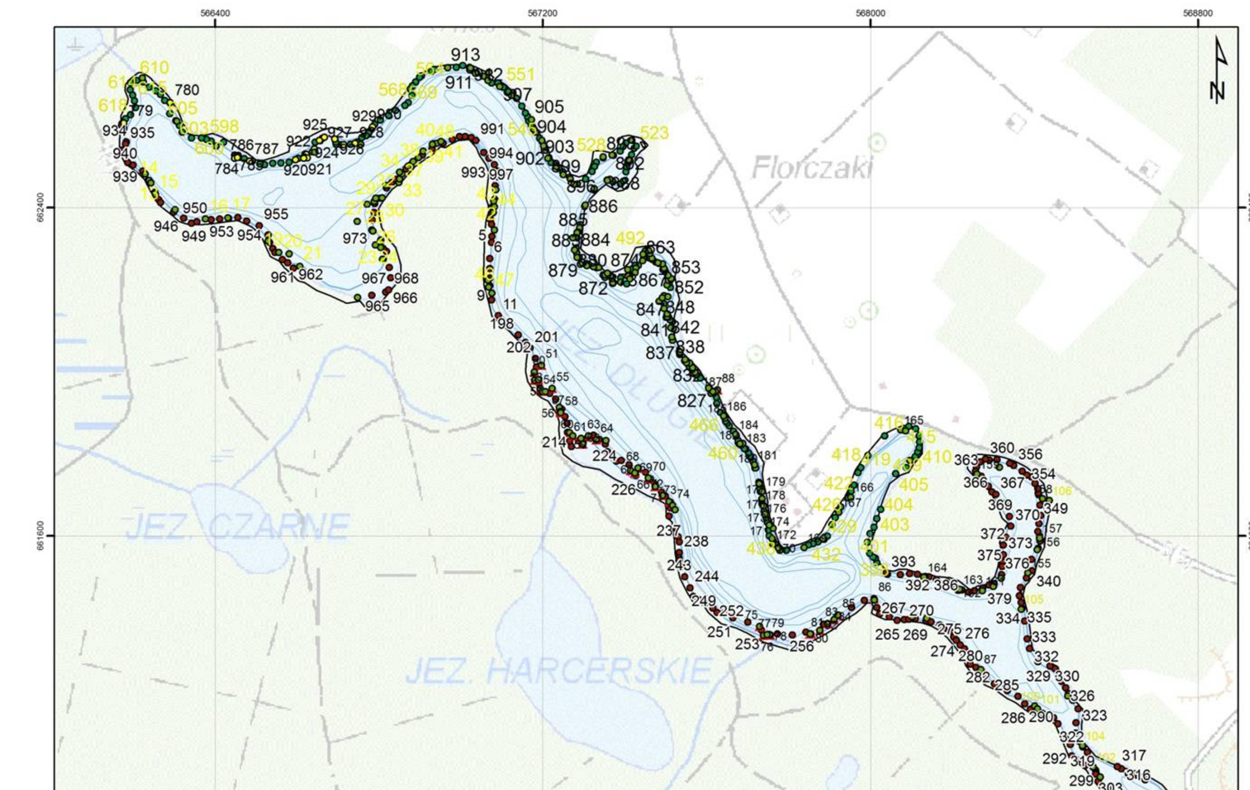

Fig. 3. Location of measurement points delineating the boundaries of plant communities.
Source: Own study

Table 4. Plant communities in Lake Długie identified using different methods.

Plant communities			Anchor method	Diving and GIS method
Charophytes	1	*Nitelletum flexilis* Corill. 1957	+	+
Elodeides	2	*Eleocharitetum acicularis* (Baumann 1911) Koch 1926	-	+
	3	*Isoëtetum lacustris* Szańk. et Klos. 1996 n.n.	+	+
Nymphaeides	4	*Nupharo-Nymphaeetum albae* Tomasz. 1977, var. *Nymphaea alba* L.	+	+
	5	*Nupharo-Nymphaeetum albae* Tomasz. 1977, var. *Nuphar lutea* (L.) Sibth. & Sm.	+	+
	6	*Polygonetum natantis* Soó 1923	+	+
	7	*Potametum natantis* Soó 1923	+	+
Helophytes	8	*Acoretum calami* Kobendza 1948	+	+
	9	*Caricetum acutiformis* Sauer 1937	+	+
	10	*Caricetum elatae* Koch 1926	+	+
	11	*Caricetum lasiocarpae* Koch 1926	+	+
	12	*Caricetum rostratae* Rübel 1912	+	+
	13	*Eleocharitetum palustris* Šennikov 1919	+	+
	14	*Equisetetum fluviatilis* Steffen 1931	+	+
	15	*Glycerietum maximae* Hueck 1931	+	+
	16	*Iridetum pseudacori* Eggler 1933 (n. n.)	+	+
	17	*Caricetum rostratae* Rübel 1912, var. Lysimachia thyrsiflora L.	+	+
	18	Ass. with *Menyanthes trifoliata* L.	+	+
	19	*Phragmitetum australis* (Gams 1927) Schmale 1939	+	+
	20	*Scirpetum lacustris* (All. 1922) Chouard 1924	+	+
	21	*Sagittario-Sparganietum emersi* R. Tx. 1953, var. *Sparganium emersum*	+	+
	22	*Sparganietum erecti* Roll 1938	+	+
	23	*Typhetum angustifoliae* (Allorge 1922) Chouard 1924	-	+
	24	*Typhetum latifoliae* Soó 1927	+	+
	25	*Thelypteridi-Phragmitetum* Kuiper 1957	+	+
Total number of communities			23	25

Source: own study.

The EU Framework Water Directive sets environmental objectives promoting the achievement of good ecological and chemical status of all types of water in the EU Member States. The above requirements cannot be met without access to reliable and accurately processed habitat data. Information about the distribution of valuable and vulnerable species and their habitats as well as systematic monitoring programs are also needed for planning purposes. In the process of developing and implementing methods for ecological status assessment, GIS has been increasingly used not only to acquire, process, and store spatial information, but also (as a supportive tool) to determine the values of the indicators proposed for water quality monitoring [22]. Such attempts have also been used in relation to macrophytes [15-18]. Rush vegetation communities can also be analyzed and described with the aid of aerial photography, which provides an excellent basis for land mapping [23, 24].

GIS tools support the development of reliable databases that contribute to sound environmental decisions and the protection of vulnerable species [18, 25-27]. Precise boundary demarcation of plant communities is necessary for environmental monitoring programs, including determinations of the succession or regression rate of submerged plants over the years. An analysis of the same transects after several years allows us to observe transformations of lake vegetation and detect changes in trophy levels. Digital maps showing the distribution of plant communities along transects should also be compiled with the use of GIS tools, in order to store environmental data.

Table 5. Indicators of macrophyte-based assessment of the ecological status of Lake Długie.

	Indicators	Anchor method	Diving and GIS method
1.	Phytolittoral area – N (%)	24	17
2.	Number of communities – S	23	25
3.	Phytocenotic diversity index – H	2.33	2.66
4.	Maximum phytocenotic diversity index – H_{max}	3.14	3.22
5.	Average maximum depth of plant colonization (m) – C_{max}	2.3	2.3
6.	Colonization index – Z	0.66	0.47
7.	Cover the bottom of the vegetation (%)	71	50
8.	ESMI	0.457	0.363
9.	Ecological status	good	good/moderate

Source: own study.

Conclusions

Classification of the ecological status of lakes using the anchor method is not suitable for evaluating the quality of lakes such as oligohumic ones (lobelian lakes), since this type must show carefull phytolittoral penetration. Fragmentary studies show that the classification of such lakes is usually a class lower than that of eutrophic lakes, and that starting conditions (reference) for this type of soft-water lakes are much better than in eutrophic lakes.

A fully automated procedure for the computation of indicators of the ecological status of lakes could be introduced if appropriate GIS tools were used. In the case of the macrophyte-based assessment method, the procedure would involve the determination of the surface area of plant communities (using data from transects), the maximum depth of plant colonization, and surface area limited by the 2.5 m isobath.

Acknowledgements

This study was carried out as part of research project NCN No. N N305 299940.

References

1. DIRECTIVE 2000/60/EC of the European Parliament and Council of 23 Oct. 2000. Establishing a Framework for Community Action in the Field of Water Policy. OJECL. 327/1.
2. Journal of Laws, **2004**, No. 168, item 1764.
3. SZMEJA J. *Isoëtes lacustris* L. Poryblin Jeziorny. In: Kaźmierczakowa R., Zarzycki K. (Eds.) Polish Red Data Book of Plants, ed. 2. Pteridophytes and Flowering Plants, Instytut Botaniki im. W. Szafera, PAN Kraków, pp.34-36, **2001** [In Polish].
4. ZARZYCKI K., MIREK Z. Red list of plants and fungi in Poland, Instytut Botaniki im. W. Szafera, PAN, Kraków, **2006**.
5. Journal of Laws of the Region of Warmia and Mazury, **2010**, No. 77, item 1244.
6. Journal of Laws, **2008**, No. 179, items 2632-2637.
7. LEYDING G. Dictionary of place-names of Mazury district, Państwowe Wydawnictwo Naukowe, Warszawa, **1959** [In Polish].
8. CHOIŃSKI A. Catalog of Polish Lakes. Part II. Mazury Lake District, Wydawnictwo UAM, Poznań, **1991** [In Polish].
9. DYNOWSKI P. Own study. **2010** [unpublished].
10. JENSÉN S. An objective method for sampling the macrophyte vegetation in lakes, Vegetatio 33 (2/3), 107, **1977**.
11. CIECIERSKA H., KOLADA A., SOSZKA H., GOŁUB M. Methodological improvements in the macrophyte-based biological monitoring of surface waters – a pilot study of waters representing selected categories and types. Stage II. Methods for field investigations of macrophytes for the purpose of routine water monitoring, and macrophyte-based assessment and classification of the ecological status of waters, Institute of Environmental Protection, Warszawa, **2006** [In Polish].
12. Regulation of the Ministry of the Environment on the classification of the state of uniform surface water bodies, of 20 August **2008**, Journal of Laws no. 162, item 1008.
13. BRAUN-BLANQUET J. Pflanzensoziologie. Springer Verlang, Wien, **1951**.
14. CIECIERSKA H. Macrophytes as indicators of the ecological status of lakes. Wydawnictwo UWM, University of Warmia and Mazury in Olsztyn, Olsztyn, **2008** [In Polish with English summary].
15. CALOZ R., COLLLET C. Geographic information system (GIS) and remote sensing in aquatic botany: methodological aspects, Aquat. Bot. **58**, 209, **1997**.
16. SCHMIEDER K. Littoral zone – GIS of Lake Constance a useful tool In Lake monitoring and autecological studies with submersed macrophytes, Aquat. Bot. **58**, 333, **1997**.
17. LEHMANN A. GIS modeling of submerged macrophyte distribution using Generalized Additive Models. Plant Ecol. **139**, 113, **1998**.
18. FLEMING J., MADSEN J.D., DIBBLE E.D. Development of a GIS model to enhance macrophyte re-establishment projects. Appl. Geogr. **32**, 629, **2012**.
19. ŹRÓBEK R., ŹRÓBEK-SOKOLNIK A., DYNOWSKI P. Application of GIS in natural sciences. Current problems

with registering submerged plants assemblages for the needs of Natura 2000 network., In: Kereković D. (Ed.) The future with GIS. Scientific monography, Nacionalna knjižnica, Zagreb, Croatia, pp. 97-103, **2011**.

20. CIECIERSKA H., KOLADA A., SOSZKA H. A Method for Macrophyte-Based Assessment of the Ecological Status of Lakes, Developed and Implemented for the Purpose of Environmental Protection in Poland. Project database BALWOIS – water observation and information system for Balkan countries. **2010**.
21. ŹRÓBEK-SOKOLNIK A., DYNOWSKI P. Preparing of cartographic documents for European Ecological Natura 2000 Network requirements. Acta Sci. Pol. Administratio Locorum, **10**, 4, **2011**.
22. Overview report of biological assessment methods used in national WFD monitoring programmes, Methods from the WaterView2 – database on assessment methods for lakes, rivers, coastal and transitional waters in Europe WISER Workpackage 2.2, available at: http://www.wiser.eu (accessed 07.02.2010)
23. VALTA-HULKKONEN, K., KANNINE, A., ILVONEN R., PARTANEN. S. Remote sensing as a tool in the aquatic macrophyte monitoring. In: RUOPPA M., HEINONEN P., PILKE A., REKOLAINEN S., TOIVONEN H., VUORISTO H. (Eds.) How to assess and monitor ecological quality in freshwaters. Nordic Council of Ministers. TemaNord **547**, 103, **2003**.
24. LEKA J. Macrophytes as a tool to assess the ecological status of lakes, in: LÄÄNE H., HEINONEN W. (Eds.). Sampling. Presentations of three training seminars about Quality Assurance (QA), Biological methods of Water Framework Directive and Waste water sampling techniques. Suomen ympäristökeskuksen moniste **328**, 60, **2005**.
25. WOODHOUSE S., LOVETT A., DOLMAN P., FULLER R. Using a GIS to select priority areas for conservation. Comput. Environ. Urban. **24**, 79, **2000**.
26. ZHANG Y., WOODWARD N. T., UNGER D., HUNG I-K, OSWALD B. P., FARRISH K. W. GIS tool for plant spatial pattern analysis. Environ. Modell. Softw. **26**, 1251, **2011**.
27. GAJOS M., SIERKA E. GIS Technology in Environmental Protection: Research Directions Based on Literature Review. Pol. J. Environ. Stud. **21**, (2), 241, **2012**.