FOLIA GEOGRAPHICA • ISSN 1336-6157 (hard copy) • ISSN 2454-1001 (online)

INTEGRATED CRITERIA FOR RANKING BLACK SEA LAND-BASED POINT POLLUTION SOURCES

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Received: June 13, 2017 | Revised: June 21, 2017 | Accepted: October 16, 2017

Abstract

The aim of the publication is to present detailed explanation of the integrated criteria developed for the Methodology for identification, assessment and ranking of the Black Sea land-based pollution sources (the Hot Spots Methodology) as well as to present results of UA land-based pollution sources ranking. The paper contains also the general description of the Hot Spots Methodology. The key focus is made on two integrated criteria for ranking of the land-based pollution sources. The first one: the degree of overall impact on water quality which characterizes the influence of waste water discharge on the environment based on the "effective" mass of pollutant and the criterion of the effect of pollutant discharge on the receiving aquatic environment. Formulae used for calculation are presented in details. The another one is the degree of local impact on water quality, which characterizes the local impact of wastewater discharge on the receiving aquatic environment taking into account the dilution of waste water by inland or sea waters. Formulae used for calculation are presented in details. Results of testing are presented by using UA official statistical data. Also general comparison of ranking 4-top UA land-based pollution sources on various criteria are presented. Interpretation: the developed criteria were integrated into the Hot Spots Methodology. The obtained data were used for compilation of the final list of 10-top UA Hot Spots and provided to the Ministry of the Environmental Protection of Ukraine as well as to the Black sea Commission.

Key words

Land-based pollution, Black Sea, Hot Spots Methodology, marine ecosystem

INTRODUCTION

Black Sea (BS) is a transboundary water body and that is why international cooperation is very important for the protection of the Black Sea ecosystem. International

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cooperation includes legislation and scientific sector which are closely connected. In 1996 Convention on the Protection of the Black Sea Against Pollution (Convention, 1996); it sets out the overall objectives and obligations of the contracting Parties (Bulgaria, Georgia, Romania, Russian Federation, Turkey and Ukraine) in Black Sea protection, the actual implementation of each of these is to be done through more detailed and specific Protocols. In 1996, the Bucharest Convention implementation was given a tight time-frame through an ambitious Strategic Action Plan (SAP (BS SAP, 2009), currently replaced by (BS SAP, 2009)) and the first regional List of BS Hot Spots (HSs) was prepared shortly before (Utkina, 2012).

Land-based pollution sources (LBSs) produce great negative impact on the Black Sea ecosystem and that is why scientists have initiated national and international projects devoted to finding ways for elimination of the pressure caused by land-based pollution sources. (Koco et al., 2016, Krzemien, 2015, Utkina et al., 2016 and Velikova et al., 2016).

During 2013-2015 under the framework of the project "Integrated hotspots management and saving the living Black Sea ecosystem" – HotBlackSea (grant agreement Nr 2.2.1.72761.225 MIS-ETC 2303, Black Sea Cooperation Programme) the Hot Spots Methodology - Guiding harmonization in identification and prioritization of Hot Spots in the Black Sea Region (the Black Sea Hot Spots Methodology or the BS HSs Methodology) was developed (Utkina et al., 2015). In preparation of this methodology, the draft Black Sea Commission HSs Methodology was taken as a basis, as well as best available practices in the development of national and regional (Arctic Seas, MEDPOL, DABLAS, HELCOM, OSPAR) methods of identification, evaluation and ranking of point sources of pollution. The aim is to provide a unified approach for identification, assessment and ranking of LBSs located in the Black sea catchment area.

PURPOSE

Before 2015 each BS country used different local/regional methodologies and criteria for identification and ranking of the LBSs. Taking into account that the Black Sea is a transboundary water body the unified methodology should be used; only in this case LBSs located in different countries can compared and obtained results will be reliable. In the framework of the HotBlackSea project such methodology was developed. The purpose of the publication is to present brief information on the Hot Spots Methodology and to present detailed information about the developed integrated criteria for ranking LBSs.

THE HOT SPOT METHODOLOGY DESCRIPTION

The Hot Spots Methodology includes the following stages of work:

Stage 1 - Compilation of full LBSs List (as full as possible);

Stage 2 - First level screening – selection of Hot Spots candidates using various indicators characterizing waste water pollution;

Stage 3 - Second level screening and first prioritization to identify top Hot Spots. Prioritization is performed on environmental and socio-economic (welfare) criteria;

Stage 4 - Third level screening to verify the prioritization according to more sophisticated criteria and build the final HSs List, which would be eligible to speak about priorities in investments and their schedule (short-, mid-, and long-term), and selection of top priority HSs.

The general algorithm of the Methodology is presented in Figure 1.

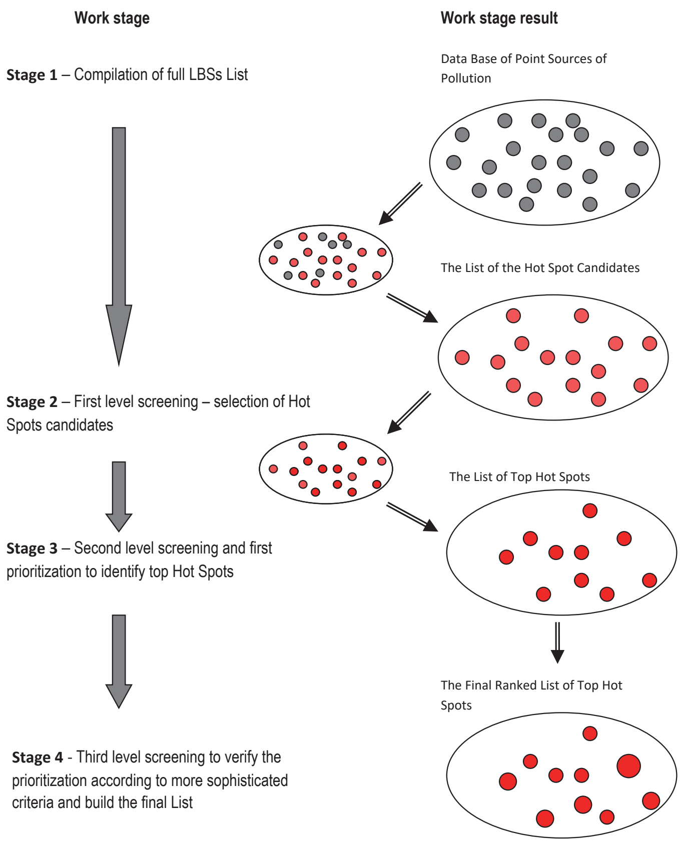

Figure 1 The general algorithm of the Hot Spot Methodology
Source: Utkina et al. (2015)

Thus, selection of Hot Spot candidates is conducted on Stage 2 of the HSs Methodology. Assessment and ranking of the Hot Spot Candidates are performed on Stage 3. Final prioritization of the Hot Spots is performed on Stage 4. It is provided in support of decision-making on investments.

At each of the stages a number of assessment criteria are used, which require additional data/information input. 'Additional' means such data/information which are not available in the LBS/HSs Database and are not automatically derived through the HS Methodology Software (see further detail explanations on the subject).

Detailed information about the Hot Spots Methodology, criteria and required data is presented at (Utkina et al., 2015).

In this publication we'd like to present information for the following two integrated criteria, which are used at the fourth stage of the Hot Spots Methodology:

- Degree of overall impact on water quality
- Degree of local impact on water quality.

INTEGRATED CRITERIA DESCRIPTION

The degree of overall impact on water quality

The degree of overall impact on water quality characterizes the influence of waste water discharge on the environment based on the "effective" mass of pollutant and the criterion of the effect of pollutant discharge on the receiving aquatic environment. Impact on the environment is evaluated on the basis of the following three factors: the effective mass of the pollutant, the coefficient of relative toxicity of pollutant and the coefficient taking into account processes of assimilation and respiration of pollutant. The value of effective mass of the i-th pollutant for Hot Spot Mx is calculated using the formula:

$$M_i = \frac{A_i \times Q_i \times C_i}{1 + K_i},$$

Where A_i is the coefficient of relative toxicity showing how many times the toxicity of the *i*-th ingredient exceeds toxicity of lignosulfonate. It is calculated according to the formula:

$$A_i = \frac{MAC_{lignosulfonate}}{MAC_i},$$

Where: $MAC_{lignosulfonate}$ = 1 mg/dm^3;
MAC_i is the maximum allowable concentration of the *i*-th ingredient in the aquatic environment;
Q_i is the wastewater discharge, m^3/year;
C_i is the concentration of pollutant in wastewater, mg/ dm^3;

K_i is the dimensionless coefficient taking into account processes of assimilation and respiration in the water body. The values of K_i for various substances are presented below.

item No.	Name of substance	Amount, K_i
1	Metal ions, pesticides, mineralization, principal ions	0
2	BOD_5, nitrates, ammonium nitrogen, phosphates, COD, oil products	1
3	Detergents, urea	10
4	Freely decaying substances (nitrites)	100

Values of MAC_I, A_i and K_i for various substances are given in(Utkina et al., 2015).

The total value of the effective mass of pollutants discharged by the Hot Spot, M_x, is calculated as the sum of individual values of the effective mass of each of the pollutants discharged into water bodies (the list of pollutants is given in the Hot Spots Methodology using the formula:

$$M_x = K_{rs} \cdot \sum_{i=1}^{n} M_i \text{ ,}$$

Where: $i = 1, \ldots ;$

n corresponds to the i-th pollutant;

n is the number of pollutants;

K_{rs} is a dimensionless coefficient;

$$K_{rs} = \begin{cases} 1, \text{ for point sourses} \\ \mathrm{N}_{rs}/365, \text{ for urban rainfall runoff} \end{cases},$$

N_{rs} is the number of days with precipitation of at least 20 mm; in the absence of information on the number of days with precipitation greater than 20 mm we accept $N_{rs} = 3$.

The index of pollutant discharge impact of the Hot Spot, M_x, on the aquatic environment (S_x) is calculated with account of the effective mass of pollutants contained in wastewaters of all discharges with the following formula:

$$S_x = \frac{M_x}{\sum_{j=1}^{k} M_j} \times 100\% \text{ ,}$$

Where: M_x is the effective mass of pollutants in wastewater of the x-th discharge, t/year;

$\sum_{j=1}^{k} M_j$ is the total amount of the effective mass of pollutants in wastewaters of all discharges, t/year;

S_x is the dimensionless quantity in percentage terms disclosing a contribution of the *x*-th discharge in the total effective mass of pollutants from all discharges;

k is the total number of wastewater discharges.

As to urban rainfall runoff, the annual mass of pollution export, (M_i), is calculated by the formula:

$$M_i = C_i \cdot Q \text{ ,}$$

Where C_i is the concentration of pollutant, (mg/l); Q is the annual rainfall runoff (m^3/year), which is calculated by the formula:

$$Q = 10 \cdot F \cdot (\varphi_r \cdot H_r + \varphi_s \cdot H_s) \text{ ,}$$

Where φ_r, φ_s are the run-off coefficients for rainfall and snow-melt waters; F is the catchment area of the territory, ha; H_r, H_s are the average annual precipitation depth for warm and cold periods, respectively, mm. Values of φ_r coefficient are assumed to be equal to: 0.3-0.4 for small towns and urban settlements, and 0.6-0.8 for large cities. Values of φ_s coefficient are assumed to be equal to 0.5-0.7 (Regulations, 1995).

Valuation assumptions (Tuchkovenko et al., 2011) for pollutant concentrations in urban surface run-off are shown below:

Parameter	**Concentration**
BOD_5	50-100 mgO_2/dm^3
Ammonia nitrogen	2.6-6.0 mg/dm^3
Phosphates	0.5-1.0 mg/dm^3
Suspended solids	1000-2000 mg/dm^3
Oil products	10-15 mg/dm^3
COD	400-600 mgO/dm^3

After calculation, S_x is assigned with the appropriate score:

Score 7	$S_x > 40$ %
Score 6	20 % $> S_x < 40$ %
Score 5	15 % $> S_x < 20$ %
Score 4	10 % $> S_x < 15$ %
Score 3	5 % $> S_x < 10$ %
Score 2	1 % $> S_x < 5$ %
Score 1	$S_x < 1$ %

In the absence of data on pollutant concentrations for the urban surface run-off (of atmospheric origin), score is assigned according to:

	If data on WW volumes are available	In the case of absence of data on WW volumes
Score 1	< 5 mln m³/year	Town population is < 500,000
Score 2	5-10 mln m³/year	Town population is 500,000-1,000,000
Score 3	10-15 mln m³/year	Town population is 1.0 – 1,5 mln
Score 4	More than 15 mln m³/year	Town population is more than 1,5 mln

The degree of local impact on water quality

The degree of local impact on water quality characterizes the local impact of wastewater discharge on the receiving aquatic environment taking into account the dilution of waste water by inland or sea waters.

The criterion of the local impact of the discharges of pollutants on the aquatic environment, taking into account the dilution of wastewater by surface (e.g. rivers, lakes) or sea waters is calculated according to the formula:

$$f_x = \frac{K_{rs}}{N_L} \cdot \sum_{i=1}^{p_x} C_{ix} / MAC_i$$

Where: C_{ix} is the concentration of the *i*-th substance in the wastewater of *x*-th source of pollution, mg/dm^3;

N_L is the reciprocal dilution of wastewater at a distance of L = 50 m from its discharge under the most unfavourable weather conditions (see further explanations);

P_x is the number of all discharged ingredients in wastewater of the *x*-th source of pollution;

K_{rs} is a dimensionless coefficient:

$$K_{rs} = \begin{cases} 1, \text{ for point sourses} \\ \mathrm{N}_{rs} / 365, \text{ for urban rainfall runoff} \end{cases},$$

N_{rs} is the number of days with precipitation of at least 20 mm; in the absence of information on the number of days with precipitation greater than 20 mm we accept $N_{rs} = 3$.

This criterion is an approximate estimate of the total MAC exceeding ratio for substances discharged by the examined source of pollution at a distance of 50 m away from the discharge point under most unfavourable weather conditions.

For discharges of waste water directly into the sea the reciprocal dilution of wastewater at a distance of L = 50 m away from the discharge point under the most unfavourable weather conditions can be calculated approximately using the following algorithm (Barannik, Kresin, 1985):

$$N_L = \frac{\Phi(z_1)}{\gamma_0 z_2},$$

Where:

$$z_1 = \frac{L + x_0}{x^* + x_0},$$

$$z_2 = \frac{q}{u \times H^2}\sqrt{\frac{D_v}{D_h}},$$

$$\Phi(z_1) = \begin{cases} z_1, & \text{for } z_1 \le 1; \\ \sqrt{z_1}, & \text{for } z_1 > 1; \end{cases}$$

$$x_0 = \begin{cases} \frac{q}{4\pi} \cdot \sqrt{\frac{D_v}{D_h}}, & \text{if } z_2 \le 1; \\ \frac{q^2}{4\pi \cdot H^2 u D_h}, & \text{if } z_2 > 1; \end{cases}$$

$$x^* = \frac{uH^2}{4\pi D_v},$$

q is the volume of waste waters, m^3/s;
L is the distance from the discharge to the nearest monitoring section, m; (L = 50 m)
x_0, x^* are the intermediate calculated parameters, m;
u is the water flow velocity in the receiving water body, m/s;
x^* is the parameter of interface of the section of two-dimensional diffusion with the section of three-dimensional diffusion, m;
D_v and D_h are the coefficients of vertical and horizontal turbulent diffusion, m^2/s, respectively;
H is the average depth at the location of discharge, m;
γ_0 is the parameter taking into account the effect of shore on reciprocal main dilution; ($\gamma_0 = 2$, if WW discharge is performed directly to the sea not far from the shoreline; $\gamma_0 = 1$, if WW discharge is performed far from the shoreline;
l_0 is the distance from the discharge to the shoreline, m.

The coefficient of horizontal turbulent diffusion, D_h, is determined by the formula from (Pukhtiyar, Osipov, 1981):

$$D_h = 0{,}032 + 21{,}84u^2$$

The coefficient of vertical turbulent diffusion is calculated using the formula from * Tarnopolskiy, 1991):

$$D_v = C_0 + C_1u + C_2H + C_3u^2 + C_4H^2 + C_5uH + C_6u^2H + C_7uH^2,$$

Where $C_0 \ldots C_7$ are constant coefficients specified in the Table 1 below.

Table 1 Values of coefficients C_i to determine the coefficient of vertical diffusion

i	**0**	**1**	**2**	**3**
Ci	$5.994 \cdot 10^{-4}$	$5.347 \cdot 10^{-4}$	$-3.681 \cdot 10^{-4}$	$-1.469 \cdot 10^{-4}$
i	**4**	**5**	**6**	**7**
Ci	$5.669 \cdot 10^{-6}$	$1.426 \cdot 10^{-4}$	$2.276 \cdot 10^{-6}$	$-2.401 \cdot 10^{-6}$

In the event, when wind currents prevail, the flow velocity under the most unfavourable conditions is taken to be equal to 0.02 m/s (***u*** = 0.02) (Falsenbaum, 1960). Similarly, in the case of non-wind (gradient) currents, in the absence of data from direct observations, the flow velocity is assumed to be equal to 0.02 m/s.

For discharges of waste water into the rivers the reciprocal dilution of wastewater can be calculated using the full mixing approximation:

$$N_L = \frac{q + Q}{q},$$

where Q – the volume of river flow.

The normalization of the criterion of local impact is performed in the following manner. Dimensionless quantity F_x is calculated. It represents the relative contribution (in percentage terms) of the *x*-th source of pollution in the total pollution of water by all selected (top) discharges:

$$F_x = \frac{f_x}{\sum_{j=1}^{p_x} f_j} \times 100\% \cdot$$

On the base of calculated values of F_x each source of pollution receives a score in compliance with.

score 7	$F_k > 40$ %
score 6	20 % $> F_k < 40$ %
score 5	15 % $> F_k < 20$ %
score 4	10 % $> F_k < 15$ %
score 3	5 % $> F_k < 10$ %
score 2	1 % $> F_k < 5$ %
score 1	$F_k < 1$ %

For urban surface run-off in the absence of data on pollutant concentrations scores are assigned according to:

	If data on WW volumes are available	**In the case of absence of data on WW volumes**
score 1	< 3 mln m^3/year	Town population is < 400,000
score 2	3-5 mln m^3/year	Town population is 400,000-700,000
score 3	5-10 mln m^3/year	Town population is 700,000-1,000,000
score 4	10-15 mln m^3/year	Town population is 1.0 – 1.5 mln
score 5	More than 15 mln m^3/year	Town population is more than 1.5 mln

It is reasonably to use two quantitative criteria characterizing pollutant loads, characterizing pressure from LBSs because of two different types of harmful impact on the sea ecosystem: local and large-scale impacts. The local impact results in increasing of pollutant concentrations in the water near the discharge point. The large-scale impact results in the contribution of sources of pollution to the formation of background concentrations and makes itself felt after a long period of time.

Quantitative criteria characterizing pollutant loads were applied already for developing different environmental programs, for example in (Barannik, Kresin, 1985; Pukhtiyar, Osipov, 1981; Tarnopolskiy, 1991; Falsenbaum, 1960; Report, 2002; WHO, 1993; DABLAS, 2003; Romanenko et al., 2003; Lloyd et al., 2004), however in that criteria the researchers did not consider two different aspects of harmful impact on the sea ecosystem from the waste water discharge source.

The both criteria that were considered above are based on pollutant loads concept. However, there is the important difference between them. The degree of overall impact on water quality criterion does not consider the processes of dilution of wastewater by sea waters, but takes into account processes of assimilation and respiration in the water body. The degree of local impact on water quality criterion on the contrary: takes into account processes of dilution of wastewater by sea waters, but disregards the processes of assimilation and respiration in the water body.

The results of criteria calculations during testing of HSs Methodology on Ukrainian LBSs are given in table 2 for 3-top Hot Spots assigned to the 1-st category (which need short-term investments).

For effective use of the Hot Spot Methodology the Hot Spot Database was developed (Velikova et al., 2015). For Ukraine the official statistical data sources were used: 2TP-vodkhoz, statistical bulletins, etc.

Table 2 The results of ranking to the 1-st category Ukrainian LBSs according to the criteria of overall and local impact on water quality for 4-top Hot Spots

Facility Name	The degree of overall impact on water quality		The degree of local impact on water quality		Total rank
	Value	Rank	Value	Rank	
Pivnichna WWTP, Odesa	17,0	2	16,5	2	1
Pivdenna WWTP, Odesa	17,5	1	16,2	3	2
Galitsinovsky WWTP, Mikolaiv	14,3	3	36,6	1	3
Sevastopol' WWTP	26,4	1	10,0	4	3

Source: Data on 2014 were used, that is why Sevastopol' WWTP is in this list, after 2014 Crimea was occupied by Russia and no data for Crimea LBSs are available

As we can see, 4-top Hot Spots determined by both criteria coincide. However the ranks determined by each criterion are different. According to the criterion "The degree of overall impact on water quality" the Sevastopol' WWTP and the Pivdenna WWTP, Odesa have the 1-st rank, because the highest masses of pollutants discharge with waste water of these point sources. According to the criterion "The degree of local impact on water quality" the Galitsinovsky WWTP, Mikolaiv has the 1-st rank, because discharge of waste water of this facility is characterized by low reciprocal dilution.

Visualization of the results are presented on Figure 2.

According to the ranking taking into account both criteria as well as other integrated criteria, Pivdenna WWTP, Odesa has the 1-st rank; this LBS is characterized by higher masses of pollutants in waste waters and lower reciprocal dilution. So the testing of developed HSs Methodology has confirmed the need of using a number of integrated criteria taking into account the different aspects of discharges impact on the sea ecosystem.

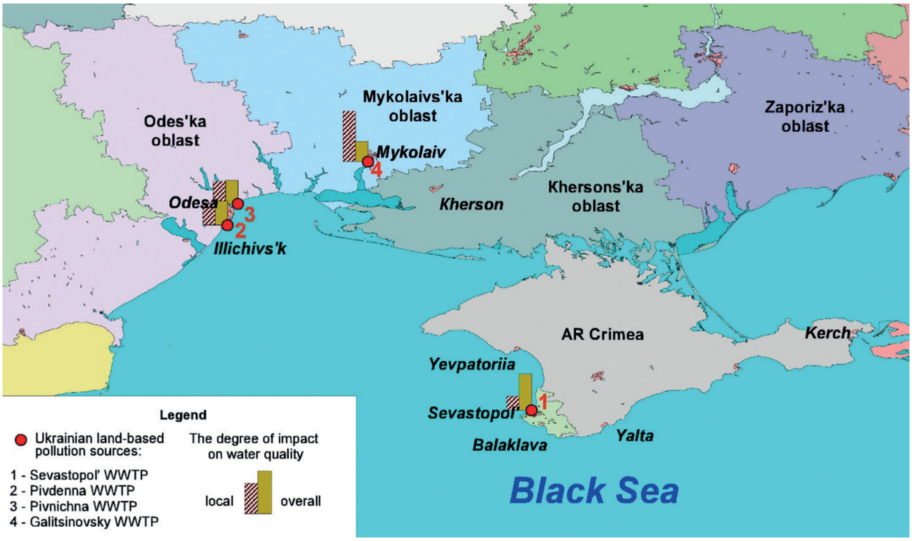

Figure 2 Four top land-based pollution sources for Ukraine

CONCLUSIONS

1. The Hot Spots Methodology of ranking has been developed for all Black Sea countries. It includes four stages and three levels of screening. On each level a set of criteria are used for evaluation and ranking of LBSs.
2. On the third level of screening several integrated criteria are included. The paper is devoted to two integrated criteria for ranking of the land-based pollution sources. The degree of overall impact on water quality characterizes the influence of waste water discharge on the environment based on the "effective" mass of pollutant and the criterion of the effect of pollutant discharge on the receiving aquatic environment. The degree of local impact on water quality characterizes the local impact of wastewater discharge on the receiving aquatic environment taking into account the dilution of waste water by inland or sea waters.
3. Both criteria are basing on pollutant loads, but have the important difference. The criteria of local impact takes into account the processes of dilution of wastewater by sea waters and the criteria of overall impact on water quality takes into account the processes of assimilation and respiration in the water body.
4. Ranking of UA LBSs has shown the following results: the Sevastopol' WWTP and Pivdenna WWTP, Odesa have the highest impact on sea ecosystem on the criterion "The degree of overall impact on water quality" (26,4 and 17,5, correspondingly); Galitsinovsky WWTP, Mikolaiv has shown the highest value on the

criterion "The degree of local impact on water quality" (36,6). However, taking into account all criteria it was proved that the Pivnichna WWTP, Odesa has the highest impact on the Black Sea ecosystem.

5. Testing of developed Hot Spots Methodology on Ukrainian LBSs has confirmed the necessity to use several integrated criteria, which consider the different aspects of LBSs impact on the sea ecosystem.

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