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ESTIMATION OF BENEFITS FROM THE ACTUAL USE OF INLAND WATER ECOSYSTEM SERVICES IN THE SLOVAK REPUBLIC

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Abstract

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The primary aim of the article is to obtain an overview of benefits from the actual use of inland water ecosystem services (ESSs) in Slovakia. The evaluation, which includes both surface water and groundwater, is primarily focused on demand side. Methods for assessing the benefits of the most prevalent ESSs, designated by Common International Classification of Ecosystem Services (CICES classification) v. 4.3, are described and discussed. The evaluation is performed at the level of 10 sub-basins to which available data are allocated. In the absence of necessary data or the impossibility of allocating them to sub-basins, the benefit from the use of some ESSs is estimated at the level of whole Slovak territory. The use of ESSs valuation in practice, especially with regard to water protection of surface water and groundwater, is discussed. The evaluation of benefits from ESSs of inland waters in Slovakia so far does not allow direct use of obtained results for proposal of measures within river basin management plans as suggested by several authors. Main reason is the input data availability and quality. At the present time, the significance of the ESSs evaluation may rather lie in the awareness of the value that human society gains from the use of inland waters. It becomes more evident that increase in environmental awareness alone is not sufficient in terms of the protection of ecosystems and their services. To achieve unambiguous and lasting improvement in this area, it is necessary to address the deeper causes, closely related to human thinking and behaviour.

Key words: inland waters, surface waters, groundwater, ecosystem services, evaluation methods, benefits.

Introduction

In the past decades, the concept of ecosystem services (ESSs) has been the subject of great attention, which confirms the wide range of publications related to different types of ecosystems – their mapping, evaluation and use or protection (e.g. Farber et al., 2006; Boyd, Banzhaf, 2007; DeGroot et al., 2010; Maes et al., 2011; Burkhard et al., 2012; DeGroot et al., 2012; COWI, 2014b; Schröter et al., 2014; Grizzetti et al., 2015a; Seifert-Dähnn et al., 2015; Maes et al., 2016).

ESSs represent the outputs of natural systems from which people have or may have benefits. The importance of water as a natural resource and aquatic ecosystems for human society

T a b l e 1. Significant ecosystem services of inland waters and related benefits from their provision in Slovak conditions (Bujnovský, 2015 – revised).

Ecosystem services		Benefits from ESSs
Surface water		
Provisional	Biomass form aquaculture	Water animals – namely, fishes
	Raw water	Water for drinking purposes, Water for crop irrigation, Water as raw material and cooling medium in industry
	Materials (the consequence of substances accumulation)	Gravel, sands (possibly riverbed sediments)
	Renewable energy	Electricity production
Regulation and maintenance	Regulation of water quality	Nitrogen retention
	Transportation medium	Ship transportation on Danube River
	Habitat preservation, biodiversity	Creation of conditions for aquatic biotopes
Cultural	Physical interaction with inland water ecosystems	Recreational activities (recreational fishing, bathing, water tourisms)
	Intellectual, symbolic and spiritual interactions with ecosystems	Object of research and education, relaxing, national identity and cultural heritage
Groundwater		
Provisional	Raw water	Water for drinking purposes, Water for crop irrigation, Water as raw material and cooling medium in industry
	Renewable energy	Source of geothermal energy
Regulation and maintenance	Habitat preservation, biodiversity	Creation of conditions for water influenced (especially terrestrial) biotopes
Cultural	Physical interaction with inland water ecosystems	Recreational activities on exposed groundwater (fishing, bathing)

results from the provision of a whole range of functions and subsequently ESSs that meet human needs, either directly or indirectly. Relevant types of benefits from these ESSs are indicated in Table 1. As stated by Schröter et al. (2014), the concept of ESSs is primarily anthropocentric, giving rise to a considerable wave of criticism as well as advocacy of the concept.

Owing to declining of ecological life-support systems in consequence of anthropogenic pressures, as pointed in many documents and papers (e.g. Millennium Assessment, 2005; EEA, 2015), there arises the need of effective protection of environment, biota inclusive.

Improving management and preventing overexploitation of natural resources, together with the value of ESSs, is one of the objectives of the renewed EU Sustainable Development Strategy. The assessment of ESSs is also enshrined in the EU Biodiversity Strategy by 2020. Achieving Goal 4 of the EU Biodiversity Strategy 2020 corresponds to a certain extent with the assessment of ecosystem services linked to inland waters (rivers and lakes).

Understanding, mapping and evaluation of benefits from ecosystem and biodiversity is considered to be the first step to enhance their protection (Maes et al., 2011) especially if they had been integrated into the relevant policies. One of these policies is also water policy, incorporated in the Water Framework Directive, and corresponds with inland waters.

There are two aspects of the evaluation of ecosystem services, namely, the supply and demand, which together determine their value (Austin et al., 2012). Even though there may be discrepancies between supply and demand parts (Burkhard et al., 2012), the actual water use (which can be considered as a proxy of demand) is easily identifiable and the relevant data can be more accessible.

Material and methods

The evaluation of ESSs of inland waters, which includes both surface water and groundwater (where relevant), is based on CICES v. 4.3 classification (Haines-Young, Potschin, 2013) and primarily focused on demand side, which indicates their actual use (see Table 1). The evaluation of ESSs, which consists of quantifying of given ESS in biophysical terms and selection of an appropriate economic valuation tool, is mainly based on relevant documents (COWI, 2014a,b; Grizzetti et al., 2015a,b) and more is described and discussed in next part. The assessment of water use suitability for a particular purpose (representing a specific ESS) is based on the assumption that the water quality complies with the relevant requirements what is actual especially for raw water for drinking purposes, water for crop irrigation, recreational fishing, bathing as well as for biomass – water animals, habitat preservation and biodiversity.

Fig. 1. Definition of sub-basins in Slovakia.

The evaluation is performed at the level of 10 sub-basins of Slovakia (see Fig. 1), to which available data (related to consumption or utilisation of water, fish catches or number of visitors) are allocated. It concerns the following ESSs:

- provision of raw water for drinking purposes,
- provision of water for crop irrigation,
- provision of gravel and sand,
- provision of renewable energy (water as medium for electricity production),
- transportation medium – ship transportation on the Danube River (relevant just for one sub-basin),
- physical interaction with inland water ecosystems – recreational fishing,
- physical interaction with inland water ecosystems – bathing.

In the absence of data, the benefit from the use of some ESSs is estimated at the level of whole territory of Slovakia and concerns the following ESSs:

- provision of biomass – water animals, namely, fishes from aquaculture,
- provision of water as raw material and cooling medium in industry (except energetic industry),
- regulation of water quality – nitrogen retention in surface waters,
- habitat preservation and biodiversity,
- intellectual, symbolic and spiritual interactions with inland water ecosystems.

The primary aim of the article is to obtain an overview of benefits from inland water ESSs used in Slovakia, which are expressed by monetary values. This is preceded by the choice of economic assessment methods and the corresponding biophysical assessment. As detecting the preferences of people and their willingness to pay for ESSs is in many cases burdened with insufficient awareness of real meaning of functions and services provided by ecosystem (e.g. Chee, 2004; Brouwer, 2008), for economic evaluation of most ESSs, non-preferential methods are used. As indicated by several articles, these methods are suitable for economic valuation of benefits from the production and regulation of ESSs (COWI, 2014a,b; Rohani, 2013; Grizzetti et al., 2016).

Results and discussion

Provision of biomass – water animals, namely, fishes from aquaculture

This ecosystem service corresponds to fish farming in watercourses and reservoirs and basically represents a purposeful anthropic regulation of the populations of selected fish species and their breeding. According to COWI (2014a,b), this ESS includes not only fish farming but also recreational fishing. In this article, recreational fishing is classified as cultural service. Estimate of the benefit from the use of this EES presupposes the availability of information on the annual production of individual fish species and their market valuation, which corresponds with approach published in COWI (2014a,b) and Grizzetti et al. (2015a).

Owing to restricted data availability, valuation of referred ESS is performed via estimation of benefit based on annual production of lowland and trout species in 2011, undertaken from National Strategic Plan for the Development of Aquaculture in Slovak Republic in the period 2014–2020 (MoA & RD, 2013), and their market valuation is estimated from the Slovak Fishing Association price list (5 and 12 €/kg of lowland and trout fish production). Indicative value of catch is subsequently reduced by the cost of artificial restocking. The benefit from the use of this ESS can be around 4 million €. As the effect of negative externalities is not taken into account, this value can be considered as overestimated.

Provision of raw water for drinking purposes

Estimating the benefit from the use of this ESS basically lies in an expression of the economic value of raw water, which depends mainly on the sufficiency of exploitable water in the water source and its quality (Elsin et al., 2010; Morris, Camino, 2011; NCGRT, 2013).

Valuation of specified ESS, performed at sub-basins level, is based on the amount of abstracted surface or ground water (data obtained from Slovak Hydrometeorological Institute) and the use of regulated market prices, which corresponds with recommended procedures (COWI, 2014a,b). Abstracted water, treated subsequently for drinking purposes, is provisionally priced in terms of price decision of the Regulatory Office for Network Industries (ÚRSO) for the Slovak Water Management Enterprise (state company) as average for the period 2011–2013 (0.1101 € m^{-3}). The same price is used for both surface water and groundwater, despite the fact that price for groundwater abstraction is three times lower in comparison to surface water. Mentioned unit price in Slovak conditions can be regarded as reasonable and comparable with abroad (Morris, Camino, 2011). The benefit from the use of this ESS, based on the mentioned approach, represents 33 million €. The relative share of individual sub-basins on the total benefit from this ESS as well as the benefit per 1 km^2 or 1000 inhabitants of given sub-basin for this ESS are illustrated in Fig. 2. The adjustment of water withdrawal prices (so far in the 5-year cycle) in the sense of the regulatory policy of the ÚRSO will be projected into a gradual increase into benefits from the use of this ESS with an assumption that water abstraction will not decrease.

Provision of water for crop irrigation

The increase in yield because of irrigation can be considered as the effect of the current use of this ESS, which depends on the availability of irrigation systems, the structure/types of crops grown and, last but not least, the economic prosperity of farms. In general, it is possible to state that the potential of water use (in Slovakia mainly surface) for irrigation is higher than the recorded water consumption for this purpose in the past 20–25 years.

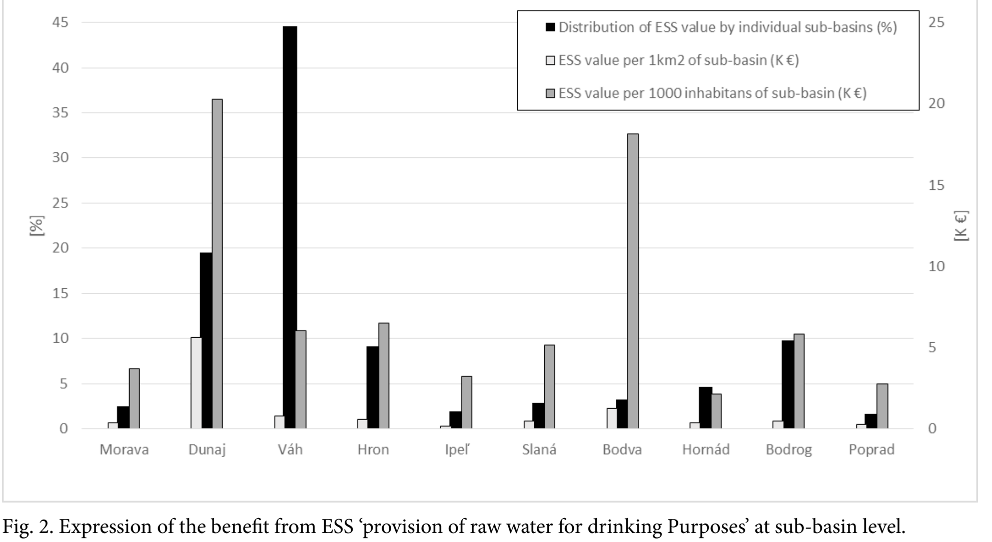

Fig. 2. Expression of the benefit from ESS 'provision of raw water for drinking Purposes' at sub-basin level.

The valuation of the given ESS, performed at sub-basin level, is based on the average amount of abstracted surface water and groundwater in the period 2011–2013 (data obtained from Slovak Hydrometeorological Institute) reduced by non-productive evaporation. Increment of dry matter plant biomass (estimated from the amount of consumed water and selected value of transpiration coefficient equal to 600 kg of water for creating of 1 kg of dry matter) is provisionally expressed by early potatoes. Average market price of this commodity during the period 2011–2013 is used to measure the effect (application of production principle). The market valuation method used corresponds with recommended approaches (COWI, 2014a,b; Grizzetti et al., 2015a).

Rental costs of irrigation and operational units as well as electricity costs associated with pumping and transport of water to lands subsequently were deducted from the economic value. This approach corresponds with the recommendation of Ward and Michelsen (2002) to separate transport costs from the cost of raw material. The benefit from the use of this ESS, based on the mentioned approach, is 25 million €. The relative share of individual sub-basins on total benefit from this ESS as well as benefit per 1 km^2 or 1000 inhabitants of given sub-basin for this ESS are illustrated in Fig. 3.

As mentioned previously, the demand capacity of the given ESS is determined by economic prosperity of farms and farming profitability. Although, during the period 2005–2016, farmers did not have to pay for the abstraction of irrigation water, its consumption did not rise, which indicates a low demand for elasticity primarily caused by high energy demand of existing irrigation systems. It is possible to assume that the irrigation water consumption in the near future should not increase significantly, also because of the gradual increase in the efficiency of irrigation systems (they often need reconstruction) as well as in terms of their cost-effective use oriented to cash crops.

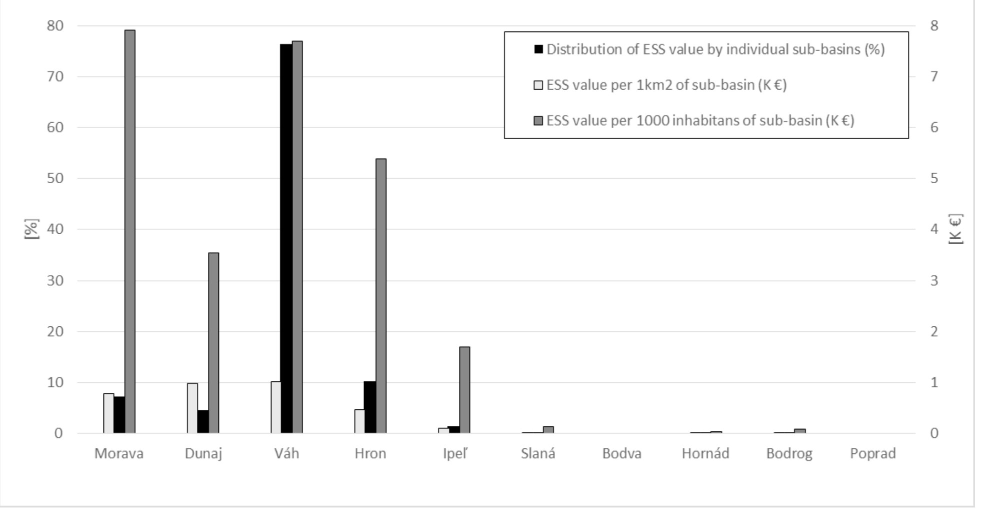

Fig. 3. Expression of the benefit from ESS ‘provision of water for crop irrigation’ atsub-basin level.

Provision of raw water as material and cooling medium in industry

Referred ESS can be assessed based on the data on water abstraction for the given purpose (data obtained from Slovak Hydrometeorological Institute), either through production or market valuation approach (COWI, 2014a,b). In the absence of information related to added value of water used in various industrial sectors (food industry, chemical industry, steel industry, etc.), the production principle is difficult to apply. Moreover, water can also be used for cooling (consumption of water in energetic industry is a separate problem that is not addressed here). For this reason, the benefit from this ESS could be roughly estimated only at national level using the indirect comparative approach. Assuming that the benefit from unit amount of abstracted water would be (preliminary) the same as from water used for crop irrigation, the benefit from the given ESS could be around 278 million €.

Nevertheless, similarly, for the estimation of resource costs within the meaning of Water Framework Directive (WFD) Article 9, in case of this ESS, the greatest benefit per unit of abstracted water can be expected. Thus the price of water supply for industrial use, recommended by COWI (2014a, b) for pricing of water used in industry, will underestimate the benefit from this ESS. It is necessary to mention that the use of this ESS is not always linked to achievement or failure to achieve good ecological and chemical status of water. On the other hand, overexploitation of water (especially the surface one) can negatively affect the ecological status of affected waters because industry together with cities and municipalities belong to sectors with major share on water abstraction in Slovakia.

Provision of gravel and sand

This abiotic ESS, designated by COWI (2014a,b) as geological sources, is based on the removal and subsequent accumulation of water-borne substances (gravel, sand or riverbed sediments) initiated by the need to remove them for the provision of shipping (maintenance of the Danube waterway) or the need for maintenance of river beds – which is part of the binding activities of the administrator of watercourses Slovak Water Management Enterprise (SVP š.p.). Provision of this ESS is not linked to achievement or failure to achieve good ecological and chemical status of water or some water quality parameters.

For the valuation of specified ESS, performed at the sub-basin, the cost method based on pricing of extracted gravel/sand is used. The data were received from watercourse administrator – SVP š.p. The effect of negative externalities (effect on life and reproduction of aquatic animals, especially fish) is not taken into account. In comparison with the previous ESS, the benefit from the use of this ESS is the smallest amongst all evaluated ones (0.6 million €). The relative share of individual sub-basins on total benefit from this ESS as well as benefit per 1 km^2 or 1000 inhabitants of given sub-basin for this ESS are illustrated in Fig. 4. After considering the negative externalities, related to the worsening of breeding and living conditions of fish species, mentioned benefit can be even lower. This negative effect is difficult to quantify, amongst other things, because in numerous fishing grounds, the fish population is regulated by man.

The riverbed sediments resulting from the surface water purification process are generally recommended to be used for the improvement of soil properties (Gunkel et al., 2015).

Their practical use is limited because the content of pollutants that are bound to the organic or inorganic fraction of these sediments usually prevents their application to agricultural land. So riverbed sediments are not included into the evaluation of this ESS.

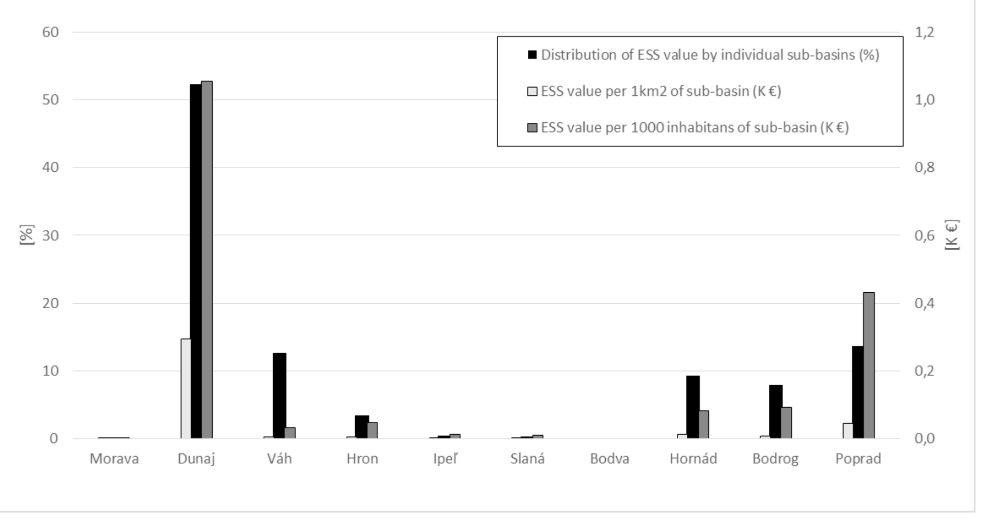

Fig. 4. Expression of the benefit from ESS 'provision of gravel and sand' at sub-basin level.

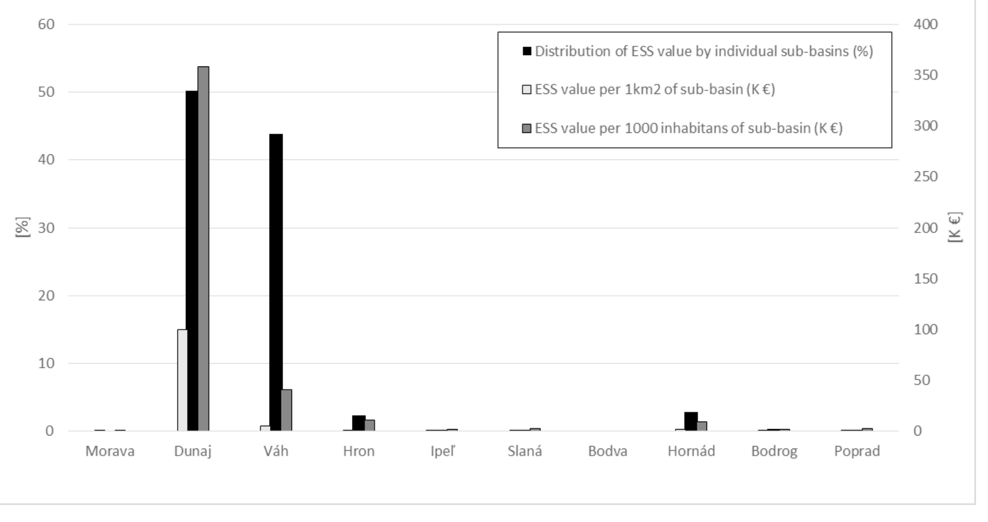

Fig. 5. Expression of the benefit from ESS 'provision of renewable energy (electricity production)' at sub-basin level.

The provision of renewable energy (water as medium for electricity production)

This abiotic ESS corresponds with the use of hydropower potential of surface waters for electricity production. The use of specified ESS is not linked to achieving or failing to achieve good ecological and chemical status of the water or some water quality parameters.

The basic prerequisite for obtaining the benefits from this type of water use is the construction of water reservoirs and installation of devices for the production of electricity. The estimation of benefit is based on the technical hydro-energetic potential of water courses on built and used hydroelectric power plants (MoE, 2011). Considered summary annual power of these plants is converted to the average wholesale electricity price in 2012.

The assessment of given ESS, performed at sub-basin level, is in line with recommended methods (COWI, 2014a,b; Grizzetti et al., 2015a), and the corresponding benefit is possible to express by market value of electricity. The benefit from the use of this ESS represents 229 million €. The relative share of individual sub-basins on the total benefit from this ESS as well as benefit per 1 km^2 or 1000 inhabitants of given sub-basin for this ESS are illustrated in Fig. 5. After considering the negative externalities, the benefit can be lower. As introduced in World Water Assessment Programme document (WWAP, 2014), generation of electricity in hydropower plants is linked to the use of water dams that cause fragmentation of river systems and adversely affect river ecology with impact on living conditions and reproduction of aquatic species, biodiversity and water quality. On the other side, dams and reservoirs may have a multi-purpose use (reduction/elimination of seasonal flooding, crop irrigation, recreation, water purification via sedimentation not excluding).

Measuring the difference in the cost of electricity generation compared to the cost of an alternative production method of production (taking into account externalities) is admittedly more objective and can provide clearly lower ESS value when the necessary data are available.

Transportation medium – ship transportation on the Danube River

Shipping belongs to the main types of water use and simultaneously (by COWI, 2014a,b) to the abiotic ecosystem services. The use of given ESS is not related to achieving or failing to achieve good ecological and chemical status of the water or some water quality parameters. The valuation of specified ESS, relevant mainly for Slovak part of the Danube, is consistent with the COWI approach (COWI, 2014a, b). The benefit estimation is based on the comparison of ship transportation with the nearest transport alternative (rail), which corresponds to the substitution method. The difference between the transport costs of shipping on the Slovak part of the Danube (estimated and provided by Slovak Cruises and Harbors, J.S.C.) and transport costs through transit rail transport at the same distance (taken from the price list of Cargo Slovakia, J.S.C. – the average for the period 2011–2013) and deducting maintenance costs for the waterway represents 67 million € per year in favour of shipping. Negative externalities from the use this ESS are not taken into account.

Regulation of water quality – nitrogen retention in surface waters

This ESS, to some extent, corresponds to the cleaning (and subsequently discharge) of waste water. Discharge of waste waters and pollutants contained therein, regulated by permits, is usually based on the principle of dilution. Both terrestrial (*ex-situ*) and aquatic ecosystems (*in situ*) are involved in surface water cleaning. Retention (reduction) of nitrogen content in aquatic ecosystems (rivers, streams, lakes) is attributed to nitrogen assimilation by suspended and benthic algae, nitrogen intake by macrophytes (which actually corresponds to the retention or accumulation) and denitrification, which, in contrary to uptake of this nutrient by the biotic component, contributes to permanent removal of nitrogen from the aquatic environment (e.g. Wollheim et al., 2006; Rode et al., 2015). Europe's nitrogen retention represents several percentage of the nutrient inputs into surface water. Therefore, in many cases, provision of mentioned ESS is only a contributory factor for nitrogen reduction in the aquatic environment that does not guarantee the achievement of good ecological status (ES) of water in terms of this nutrient/substance, as evidenced by the information of Maes et al. (2011) and Grizzetti et al. (2015b).

Owing to the unavailability of data, only a rough estimate of relevant benefit on the level of Slovakia is performed. The evaluation of this ESS is in line with the indicator nitrogen retention or the amount of removed pollutant specified in several documents (COWI, 2014a,b; Grizzetti et al., 2015a,b). The valuation of the ESS in question by the substitution method corresponds to the estimated costs of alternative ways to reduce this nutrient in the aquatic environment, which are either the costs of wetland constructing or the costs of floodplains restoration (e.g. Grossmann, 2012; La Note et al., 2012).

At the selected nitrogen retention rate of 4 kg $N.ha^{-1}$ per year (estimated based on data by Seitzinger et al., 2006) in the river network and in the reservoirs, the economic value (benefit) of this ESS is preliminarily estimated at 3 million €.

Habitat preservation and biodiversity

This ESS does not have a direct link to securing the main types of water use (e.g. drinking water supply, collection and treatment of wastewater, water use in industry, water use in agriculture, water transport, fisheries), but it can be affected by them. Achieving good ecological and chemical status of water (postulated by EU Water Framework Directive) is one of the preconditions for ensuring the protection of (natural and affected) habitats. Estimating the benefit from the use of this ESS is currently problematic. From economic methods, as stated in COWI (2014a, b), the preference method of 'willingness to pay' is recommended in this case. As indicated by Chee (2004), the results obtained by preference methods can be greatly distorted because of the lack of awareness/knowledge of respondents on real significance of the function(s) and consequently of the ecosystem. Another possibility is to use expert methods (Seják et al., 2010) in which setting the value (related to one point) is based on the costs of already implemented revitalisation measures.

Owing to the unavailability of necessary data, only a rough estimate of relevant benefit from surface waters on the level of Slovakia is performed. It is assumed that the conditions for fish life (which are at the top of the food chain in aquatic ecosystems – regardless of aquatic birds and some mammals living in the aquatic environment) and then their populations reflect environmental conditions and biodiversity. The annual cost of restocking fishing grounds (undertaken from Slovak Fishing Association) are used for the estimation of the given ESS benefit, which is about 5 million € per year.

Physical interaction with inland water ecosystems – recreational fishing

The use of this ESS, which belongs to provisional services, is linked to fishing grounds. Within both surface water and underground water, currently in Slovakia, nearly 1200 fishing grounds is defined, of which the vast majority is administered by the Slovak Fishery Union.

The valuation of specified ESS, performed at sub-basin for surface water and groundwater in 2012, is based on the catch of concrete species and their valuation based on the pricelist of the Slovak Fishery Union with the deduction of the restocking cost. This approach corresponds with now recommended methods so far (COWI, 2014a, b; Grizzetti et al., 2015a). The effect of negative externalities is not taken into account. The benefit from the use of this ESS, calculated based on the mentioned approach, is 3 million €. The relative share of individual sub-basins on total benefit from this ESS as well as benefit per 1 km^2 or 1000 inhabitants of given sub-basin for this ESS are illustrated in Fig. 6.

Owing to the fact that the fish populations are usually purposefully influenced and targeted in the fisheries areas of the Slovak Republic (artificial restocking, feeding of fishes), the information regarding the benefits from the use of this ESS in the form of catches is overestimated, not giving an objective picture of the potential of the natural environment in this respect.

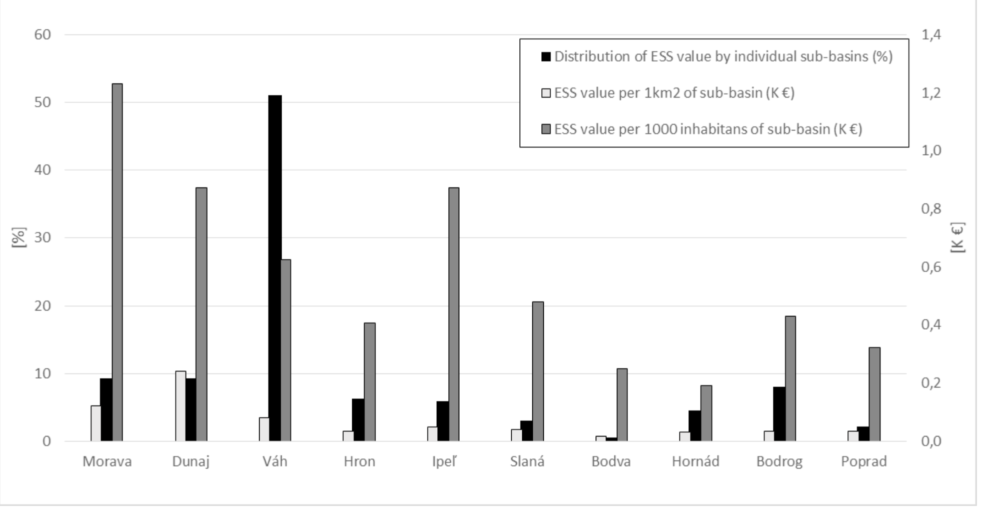

Fig. 6. Expression of the benefit from ESS 'physical interaction with inland water ecosystems – recreational fishing' at sub-basin level.

Physical interaction with inland water ecosystems – bathing

Some natural water areas (water reservoirs and exposed groundwater) are used for bathing and recreation. These water areas are defined by national legislation (Act. No 355/2007 Coll.). The list of waters/locations suitable for bathing is updated annually with respect to the results of the particular monitoring performed by national Public Health Authority.

For the valuation of referred ESS, performed at the level of sub-basins for surface water and groundwater in 2011–2013, usually the preferential methods (e.g. travel cost method or derived from visitor incomes to recreational sites – factor income of the area of recreation) are often recommended (COWI, 2014a,b; Grizzetti et al., 2015a). Fees for the use of natural swimming pools (entrance fee) represent another way to estimate the benefit what corresponds with market valuation method. However, it should be noted that the crucial item of the entrance fee (in the case so-called 'operated natural pools') are services provided by the operator and not by natural water pool. In the case of remaining natural bathing waters, approved by national legislation, we can consider only a rough estimate of the potential fees because access and subsequent use of water pool is free.

Another alternative for recreationists is the use of artificial pools whilst bathing water (except for the thermal pools) is often taken from the public water supply systems. Cost savings for water and sewerage (substitution method) represent the immediate benefit of the use of natural waters, which represents approximately 1 million €. The relative share of individual sub-basins on total benefit from this ESS as well as benefit per 1 km^2 or 1000 inhabitants of given sub-basin for this ESS are illustrated in Fig. 7.

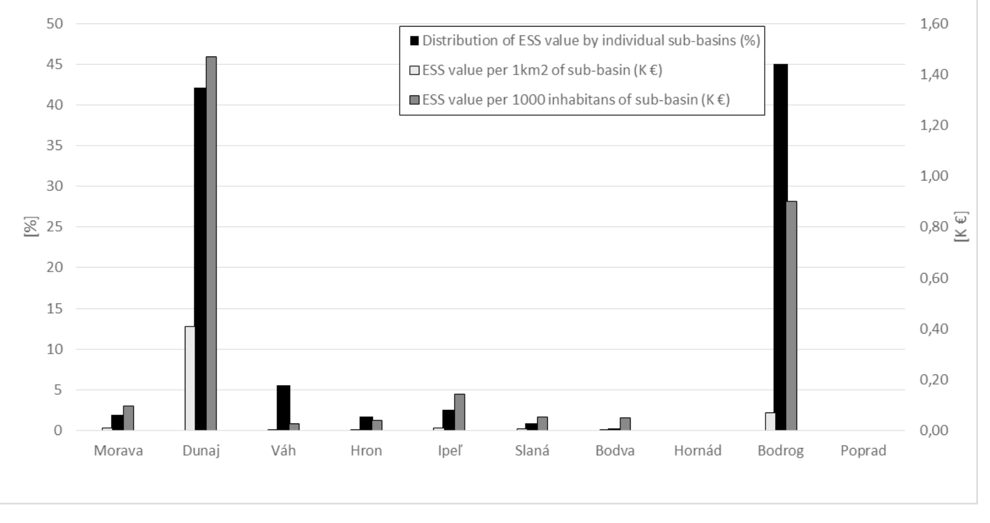

Fig. 7. Expression of the benefit from ESS 'physical interaction with inland water ecosystems – bathing' at sub-basin level.

Intellectual, symbolic and spiritual interactions with inland water ecosystems

For the evaluation of specified ESS, the preferential methods (e.g. willingness to pay) are recommended (e.g. Grizzetti et al., 2015a). In essence, these methods provide a hypothetical benefit value of the ESS in question. As mentioned earlier, people and their willingness to pay for ecosystem services are in many cases burdened with a lack of real meaning of services that given water ecosystem provides. Moreover, potential and even real payment undoubtedly depends on socio-economic factors or living standard of the population. With respect to the long-term decline in the purchasing power of the population or decline in household consumption, which is amongst the lowest in the European Union (Morvay et al., 2014), it can be expected that the benefit from this ESS, related to surface water, will be rather symbolic (estimated less than 1% of total benefit from all evaluated inland water ESS or comparable to benefit from physical interaction with inland water ecosystems).

As stated by Cooper et al. (2016), people have the benefits of their aesthetic and spiritual experiences in nature. Aesthetic and spiritual values do not have the character of individual preferences and are often socially shared values. They are also not primarily instrumental (in terms of the benefits of an individual or group), but they are constitutive and relational. As a result, it is not about a service of nature for man, but it is about forming a responsible relationship of man to nature.

Some remarks to evaluation of inland water ecosystem services

There is necessary to distinguish between the methods of evaluation and the goals that correspond with driving forces and pressures related to environmental damage. The trajectory can be described as damaged environment → mapping the state and evaluation of benefits (or lost benefits) from ESSs (in this case inland water ecosystems) → implementation of measures under the relevant policies that can return the affected environment to desired state.

Data availability or their estimation via modelling is a general problem that significantly affects the ESSs mapping and benefits estimation. As mentioned in introductory part, understanding, mapping and evaluation of benefits from ecosystems is considered as the first step to enhance their protection, which implies their consideration in the implementation of relevant policies. One of these policies is also water policy, incorporated in the Water Framework Directive.

In principle, achievement of WFD environmental objectives has positive impact on the preservation of habitats and biodiversity. Eventual improvement in the status of waters is the goal of the European Union's current policy; however, the term 'ecosystem services' is not defined in WFD. So many documents (e.g. COWI et al., 2014a,b; Vlachpoulou et al., 2014; Grizzetti et al., 2015a; Grizzetti et al., 2016) try to identify the incorporation of ESSs assessment into water policy. For example, ESSs assessment can be used for potential application of derogations under Article 4 of the WFD, selecting cost-effective measures (Article. 11 WFD) and also designing of measures beyond legislative requirements and limits within payments for ESSs. The evaluation of benefits resulting from the ESSs of inland waters or benefits that are lost when necessary measures are not implemented (and good status of waters is not reached) is one of the ways for the estimation of external costs of environmental damage – environmental costs and resource costs what follows from Article 9 of the WFD (Brouwer, 2004). These costs can/should be taken into account for the application of WFD cost recovery principle. Before that, however, it is necessary to have a picture of the capacity of the environment (supply) as well as the effect of the good status of waters or water quality parameters on individual ESSs. Another problem is disaggregation of capacities of individual ESS into water bodies through modelling because there are no direct data. As introduced by Keeler et al. (2012), the use of water and landscape affects water quality and subsequently the capacity of services of water and aquatic ecosystems. As the relation between the change in load environment and changes in service capacity of water and aquatic ecosystems is hardly predictable, the proposal of measures related to the improvement of ecosystem services seems quite problematic. Seifert-Dähnn et al. (2015) pointed to several shortcomings in the use of ecosystem services approach in the implementation of the WFD. Challenges include both methodological (namely, selection of proper valuation method, proper consideration of the trade-offs and side effects) and practical parts. Not insignificant is also the fact that existing evaluation is often very diverse and quite time consuming especially with regard to data acquisition from different sources. Moreover, practical use of ESSs valuation presupposes the use of models that should allow to consider trade-offs and side effects of specific measures.

As published earlier (Bujnovský, 2015) and in previous text, achievement or failure of good ecological status of waters does not always correspond with the provision of ecosystem services. Ecological status of waters is often considered as an expression of the quality of structure and functions (and consequently services) related to aquatic ecosystems that are linked to surface water. As some services of water and aquatic ecosystems are not linked to the achievement of good ecological/chemical status, this fact (in previous sentence) has a relative validity. In addition, some types of water use have designed specific and different qualitative objectives (e.g. surface water for drinking purposes, water for crop irrigation, etc.). Therefore, direct comparison of the value of the lost ESSs with the costs of the measure(s) to reach a good ecological status could be misleading.

Consideration of indicators for evaluating the specific ESSs does not always reflect the nature/principle on which ecosystem is based. For example, indicators such as 'trophic status', 'ecological status' and 'treated wastewater' do not correspond at all with self-cleaning ability of water. Mentioned problem is also reminded by Maes et al. (2016) who say that the fundamental problem of a complete assessment of the ESSs are insufficient data, leading to the use of such indicators which rather reflect pressures on ecosystems than the contribution of ecosystems to regulation and maintenance.

Economic assessment of ecosystem services raises much discussion regarding their potential commodification (e.g. Gómez-Baggethun, Ruiz Pérez, 2011). As Hahn et al. (2015) introduced, demonstrating the value of nature in the financial terms brings the aspect of comparability or interchangeability. This may also be the basis for determining the fees or subsidies for the improvement of ecosystems and related services, although in many cases payments for improvement of ecosystem services are compensations for loss of profit. According to Seifert-Dähnn et al. (2015), biophysical and subsequently monetary valuation can serve as the base for eliciting the importance of individual services.

Not insignificant is even the fact that the financial statements on ESSs values call for the integration of these values into reporting systems and national accounting (e.g. Hahn et al., 2015; La Note et al., 2017), which potentially may affect the tax burden on population in the future.

At the present time, the significance of the ESSs evaluation may rather lie in the awareness of the value that human society gains from the use of inland waters. According to Schröter et al. (2014), the economic evaluation provides additional information to support decision making but does not replace ethical, environmental or other non-monetary arguments.

It appears that increase in environmental awareness alone is not sufficient in terms of the protection of ecosystems and their services. As stated by OECD (2017), solving of environmental problems requires behavioural changes in human.

As stated by Bujnovský and Vilček (2011), to achieve unambiguous and lasting improvement in this area, it is necessary to address deeper causes, closely related to human thinking and activities. Without thorough knowledge of the real problems, we still solve only symptoms and not the roots. One of the basic reasons of existing environmental problems lies in growing consumption. Instead of meeting the needs, people are trying to satisfy their desires, which are infinite.

There exist more societal forces and phenomena that directly or indirectly affect state and evolution of the environment, and so they become politically significant. Besides economic, political, social and cultural factors, market, advertising, demographic factors and technical developments, it is necessary to mention human convictions, beliefs, values, attitudes and behaviours at the level of individuals, households, communities and whole public (Bechtel and Churchman, 2002; Stern, 2000). Attitudes and behaviours with regard to environment are often reflected in relevant emotions (De Miranda Coelho et al., 2016). People like to overstate the problems or some likes to underestimate. So subjective perceiving of environmental problems together with emotions cannot replace a thorough understanding of the causes of environmental problems and their real solutions. The post-truth world, appealing on emotions, is the real evidence of that.

Conclusion

The primary aim of the article is to obtain an overview of benefits from actually used inland water ESSs in Slovakia. The evaluation of both surface and ground waters (where relevant) is based on CICES v. 4.3 classification and is primarily focused on demand side, which indicates their actual use. The assessment of water use suitability for a particular purpose (representing a specific ESS) is based on the assumption that the water quality complies with the relevant requirements what is actual in the case of ESSs relevant to water quality.

The evaluation is performed at the level of 10 sub-basins. In the absence of data, the benefit from the use of some ESSs is estimated at the level of whole territory of Slovakia. This is preceded by the choice of economic assessment methods (mainly non-preferential ones) and the corresponding biophysical assessment.

The use of ESSs valuation in practice, especially with regard to water protection of surface water and groundwater, is discussed. Ecological status (ES) of waters is often considered as an expression of the quality of structure and functions (and consequently services) related to aquatic ecosystems that are linked to surface water. As some services of water and aquatic ecosystems are not linked to the achievement of good ecological/chemical status, this fact has a relative validity. In addition, some types of water use have designed specific and different qualitative objectives (e.g. surface water for drinking purposes, water for crop irrigation, etc.).

The evaluation of the benefits from ESSs of inland waters in Slovakia so far does not allow direct use of obtained results for proposal of measures within river basin management plans as suggested by several authors. The main reason is the input data availability and quality.

At the present time, the significance of the ESSs evaluation may rather lie in the awareness of the value that human society gains from the use of inland waters. It becomes more evident that increase in environmental awareness alone is not sufficient in terms of the protection of ecosystems and their services. To achieve unambiguous and lasting improvement in this area, it is necessary to address deeper causes, closely related to human thinking and behaviour.

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PHYTONCIDE ACTIVITY OF WOODY PLANTS UNDER THE CONDITIONS OF STEPPE ZONE

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Abstract

Volodarets S., Glukhov A., Zaitseva I.: Phytoncide activity of woody plants under the conditions of steppe zone. Ekológia (Bratislava), Vol. 37, No. 3, p. 219–229, 2018.

The study of phytoncide activity of biogenic volatile organic compounds of woody plants is one of the most important areas of research in plant ecology in urban lands. The aim of this work is to investigate the dependence of the phytoncide activity of some woody plant species from meteorological factors in the urban environment in the steppe zone of Ukraine. The objectives of the investigation were 28 species of trees and shrubs. The air temperature is indicated to be a major factor for drought-resistant and some medium drought-resistant species (*Populus simonii* Carrière, *Armeniaca vulgaris* L., *Robinia pseudoacacia* L., *Acer pseudoplatanus* L., *Malus niedzwetzkyana* Dieck). The phytoncide activity of low and medium drought-resistant species (*Viburnum opulus* L., *Acer sacharinnum* L.) depends on air humidity and total monthly precipitation. The obtained results make it possible to predict changes in the phytoncide activity of woody plants, when selecting the assortment of species for phyto-optimization of technogenic environment.

Key words: woody species, antiprotozoal activity, temperature, humidity, precipitation, arid zone.

Introduction

During their vital activity, woody plants release biogenic volatile organic compounds (BVOC) into the air, which are a volatile form of phytoncides. Phytoncides are one of the many factors, influencing the air microflora composition under the conditions of different plant associations, and regulate the composition of living organisms in biogeocenosis. These compounds regulate the interaction of organisms in the urban environment and maintain the balance of pathogenic microflora in the air of the city. They also limit the rising of pathogenic microflora for human.

Ability of BVOC to suppress the growth and development of bacteria and protozoa – phytoncide activity (PA), depends on meteorological factors, phenological phase and vital condition of a plant. The ability to produce phytoncides is closely related to the age of plants, their development in ontogenesis, and has seasonal nature, that is, in different seasons and vegetative phases, different organs of the same plant have different activities (Fuentes et al., 2000; Duhl et al., 2008; Dewulf et al., 2012).

The largest amount of volatile compounds with high phytoncide activity is secreted by the young organs of plants. As their age increases, this activity decreases (Pennuelas, Llusia, 2001). A more complex dependence is observed depending on the age and the vegetative phase of plants. Along with photosynthetic activity and growth processes, an important role is played by an increase in the mass of the assimilation apparatus of plants (Kesselmeier, Staudt, 1999).

Volatile organic compounds are synthesized as secondary metabolites in the cytoplasm and cell organelles of plants. Biogenetic precursors of these compounds are: mevalonate, acetyl-coa, cinnamic acid and amino acids. Water-soluble compounds accumulate in vacuoles, whereas gaseous and lipophilic substances are emitted into the free space of a cell, from where they are extracted out of the plant organism (Roschina V.V., Roshchina V.D., 2012; Harley, 2013; Harley et al., 2014).

The research area is located in the southeast of Ukraine with complex forest vegetation and technogenic conditions (State of the Natural Environment, 2010). High temperatures and insufficient precipitation have weakened woody plants; therefore, forest communities do not treat a zonal type of vegetation of a steppe zone. In such conditions, the problem of influence of abiotic factors (temperature, humidity and precipitation) on the emission of secondary metabolites, particularly phytoncides, as one of the expressions of vital activity of the plant organism, is important and promising. This question is especially relevant for the urbanized (industrial) territories, as it has been established through previous researches that in the conditions of aerogenic contamination, drought-resistant species find out greater firmness exactly at which the mechanisms of adaptation to the drought operate in the conditions of industrial pollution, as preadaptations to aerotoxicants (Fowler, 2002; Hopke, 2009; Korshikov, 2004; Kulagin, 1985).

The BVOC emission, particularly isoprenes and monoterpenes, depends on the light intensity and air temperature (Davison et al., 2009). Mathematical models were developed to calculate the amount of isoprenes, emitted by trees, for example, MEGAN (Guenther et al., 2006; 2012).

In the CIS countries, the models for influence of abiotic factors (light, temperature and humidity) on phytoncide activity were developed only for *Quercus rubra* L. and *Pinus kochiana* Klotzsch ex K. Koch (*P. hamata* [Steven] Sosn.) (Slepyih, 2004). Since the phytoncide activity depends on the microclimatic conditions of woody plant growth, it is essential to take into account the influence of meteorological factors during the investigation of BVOC at the regional level to determine the influence of temperature and humidity on the phytoncide activity of woody plants and to build a statistical model for species with the highest phytoncide activity. The purpose of this paper was to find out the dependence of phytoncide activity of woody plants on weather conditions in the region of a steppe zone, to carry out its quantitative assessment and to construct the prognostic statistical model of a temperature effect, air humidity and an amount of precipitation on the phytoncide activity for some species.

Material and methods

The objects of research were 28 species of deciduous plants. They grow on sites of the Donetsk Botanical Garden of the NAS of Ukraine, which is located beyond the main sources of pollution.

According to the physical and geographical regionalization, the research area belongs to the north-steppe subzone of the steppe zone (Lipinskogo et al., 2003). The climate of the research area is moderately continental of the mid-latitude steppe, characterized by aridity during the summer. The humidity coefficient is about 0.8, the annual precipitation is from 440 to 460 mm, including that of the warm season from 216 to 290 mm.

As shown in Figure 1, the investigation was conducted during two vegetative periods that contrasted on precipitation and temperature – in the condition of a long dry period and in the related normal conditions for the investigated region for hydrothermal regime, in the example of years 2010 and 2011.

The plant material was collected monthly at solar windless weather from May to September. For the study, we took healthy, undamaged leaves, without signs of chlorosis, around the perimeter of the crown (from the southern, northern, eastern and western parts), from the lower layer. The leaves were collected from 7–8 trees to obtain the average sample.

The monthly temperature, humidity and the sum precipitations for Donetsk were used during the investigation from Ukraine National Hydro Meteorological Center (Ukrayinskii hidrometeorolohichnyi tsentr).

When determining the growth stages of deciduous plants, we used the method of visual observation (Zaitseva, 2003; Methodology of phenological observation, 1979). We distinguished the following development phases of the

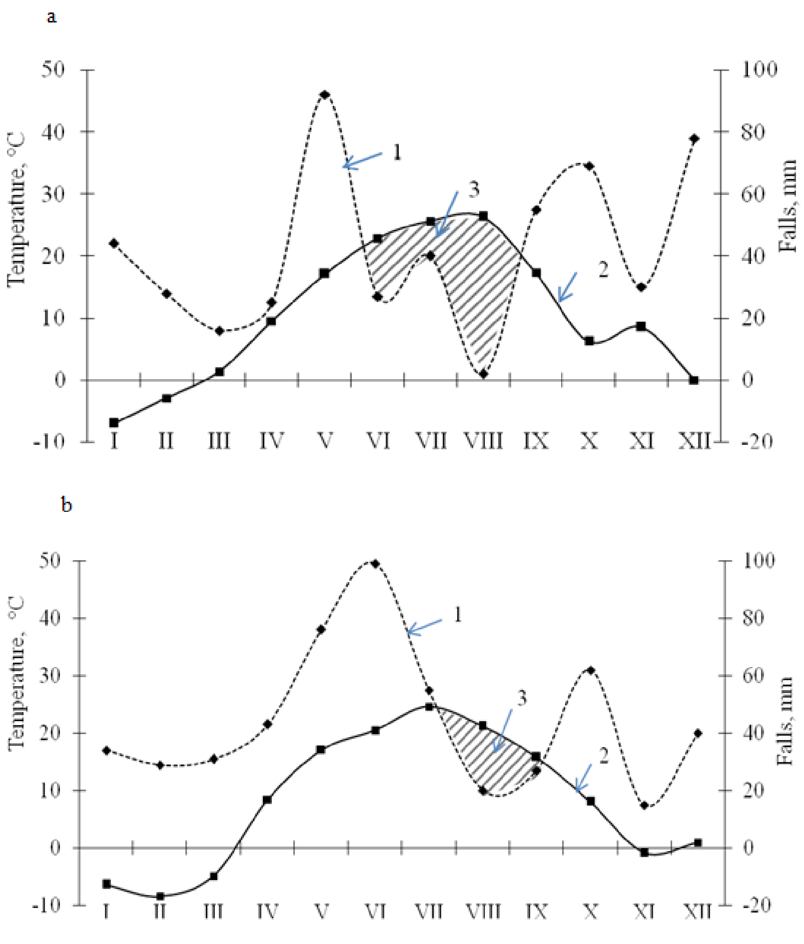


Fig. 1. Walter-Lieth climate diagram in Donetsk in the years of research: a – 2010, b – 2011.
Notes: 1 – the value of the amount of precipitation for month, mm, 2 – the value of monthly average temperature, °C, 3 – drought period.

woody plant shoots: the phase of active growth (from the leaf-out, beginning of shoot growth), the phase of secondary growth (end of shoot elongation, formation of the apical bud, summer vegetation), the phase of deep (physiological) rest – suspension of all growth processes in the late summer and early autumn. The terms of phenological changes were recorded in days after the first of March from starting the positive temperatures (Zaitseva, 2003). The investigated species have changed the term of growth period from 129 to 222 days.

The antiprotozoal activity of leaves was determined according to the 'hanging drop' technique (Tokin, 1980), in 5 times. We used the culture *Paramecium caudatum* Ehr. as a test object. With a total arrest of motion, we stated the death of *P. caudatum*, followed by the granular decay of its body.

Phytoncide activity was calculated from the formula:

$$A = 100/T\ (\text{min}^{-1}),$$

where A is phytoncide activity in terms of phytoncide ability – min^{-1}, T is time of death of 50% *P. caudatum* (Grodzinskiy, 1973).

Mathematical treatment of the data was conducted by the single-factor analysis of variance (ANOVA), using the Tukey's test and Levene's test. Next, we determined the relationship between the average monthly indicators of meteorological factors (temperature, humidity and precipitation) and the average monthly phytoncide activity with the use of stepwise regression analysis. Then, we defined the Durbin-Watson statistic and a serial correlation in Statistica 10.0.

Results and discussion

As a result of the ANOVA analysis, it was stated that the character of phytoncide activity varies during the vegetative season and is species-specific as shown in Table 1 and Table 2. Based on the Tukey's posteriori analysis, we distinguished a group of woody plants having the maximum PA in a certain vegetative phase: in the phase of active shoot growth (*Padus avium* Mill.), in the phase of secondary shoot growth (27 species) with the maximum in June – *Populus* × *canadensis* Moench and *Malus niedzwetzkyana* Dieck, in July – 10 species and 13 species in August. *Ulmus laevis* Pallas. don't have a maximum, and *Sorbus intermedia* (Ehrh.) Pers have the maximum PA in July and August.

As shown in Table 3, the factors influencing PA are heterogeneous according to the results of stepwise regression analysis for the first group.

For *Padus avium*, which is an exception to the general pattern, the major factor is precipitation ($B > 1$), as this species likes moisture conditions. According to the ecomorphological relation to the moisture, *P. avium* is mesophyte. 146% of normal precipitation fell in May 2011.

P. avium sensitively reacts to the favourable conditions of humidifying by an increase of the level of the vital activity. This possibility is reflected at an increase of its phytoncide activity. Moreover, the major factor is a vegetative phase. This dependence is shown by the means of two equations of regression with two variables: phenophase and air temperature; phenophase and amount of precipitation as imaged in Figure 2 a, b, with $R^2 = 0.91$ and $R^2 = 0.83$. For other species, we constructed laniary dependence between temperature and humidity or precipitation, or influence only of temperature is established. For *P. avium*, the impact of phenophase is exactly determined, as for mesophilous species according to the moisture.

The antiprotozoal activity of this species positively correlates with the rising of the temperature in the period of active growth of vegetative organs – the shoots and leaves. In the phase of secondary shoot growth (July, 146 days), PA decreases, because initial substances forming BVOC are used during the fruiting period of *P. avium.* This tendency can be explained by the chemical

T a b l e 1. Antiprotozoal activity (min^{-1}) of deciduous woody plants in hydrothermal conditions, typical for the area of researches, M ± m, n = 5, all the data is significant at $p \leq 0.05$, bold type – antiprotozoal activity peak.

№	Species	Months				
		May	June	July	August	September
1.	*Betula pendula* Roth	5.4 ± 0.20	6.2 ± 0.48	**6.4 ± 0.20**	5.9 ± 0.12	3.8 ± 0.07
2.	*Junglans regia* L.	8.2 ± 0.47	10.8 ± 0.49	**13.2 ± 0.54**	13.6 ± 0.93	12.1 ± 1.10
3.	*Populus bolleana* Lauche	5.5 ± 0.14	6.0 ± 0.18	**6.3 ± 0.19**	5.2 ± 0.10	4.9 ± 0.11
4.	*P.* × *canadensis* Moench	5.7 ± 0.21	**7.5 ± 0.17**	6.8 ± 0.27	6.0 ± 0.19	5.5 ± 0.64
5.	*P. simonii* Carrière	6.5 ± 0.22	8.4 ± 0.34	**14.4 ± 0.67**	7.8 ± 0.31	5.7 ± 0.22
6.	*Salix alba* L.	4.3 ± 0.12	5.3 ± 0.15	**7.0 ± 0.13**	4.5 ± 0.14	3.2 ± 0.07
7.	*Tilia cordata* Mill.	7.4 ± 0.23	6.2 ± 0.13	**13.8 ± 0.44**	12.1 ± 0.46	6.5 ± 0.18
8.	*Ulmus pumila* L.	3.5 ± 0.08	4.7 ± 0.11	5.4 ± 0.15	**6.5 ± 0.19**	3.8 ± 0.10
9.	*U. laevis* Pallas	1.4 ± 0.02	1.6 ± 0.02	1.5 ± 0.03	1.4 ± 0.02	1.3 ± 0.02
10.	*Morus alba* L.	1.7 ± 0.02	2.4 ± 0.03	**3.2 ± 0.07**	1.8 ± 0.02	1.7 ± 0.03
11.	*Armeniaca vulgaris* L.	8.0 ± 0.36	9.0 ± 0.35	8.4 ± 0.27	**11.9 ± 0.39**	6.7 ± 0.41
12.	*Malus niedzwetzkyana* Dieck	4.7 ± 0.09	**6.2 ± 0.11**	5.6 ± 0.22	5.2 ± 0.17	4.3 ± 0.13
13.	*Padus avium* Mill.	**12.4 ± 0.51**	8.5 ± 0.37	6.3 ± 0.19	6.6 ± 0.29	5.1 ± 0.09
14.	*Pyrus communis* L.	6.6 ± 0.24	7.7 ± 0.19	9.0 ± 0.41	**14.6 ± 0.83**	8.2 ± 0.35
15.	*Sorbus aucuparia* L.	5.2 ± 0.23	6.1 ± 0.21	6.8 ± 0.42	**8.3 ± 0.45**	4.7 ± 0.15
16.	*S. intermedia* (Ehrh.) Pers	4.6 ± 0.10	5.0 ± 0.23	5.6 ± 0.22	5.6 ± 0.15	4.3 ± 0.15
17.	*Robinia pseudoacacia* L.	5.7 ± 0.13	8.8 ± 0.27	7.3 ± 0.26	**10.4 ± 0.53**	4.9 ± 0.18
18.	*Aesculus hippocastanum* L.	4.2 ±0.09	5.8 ± 0.21	**8.6 ± 0.18**	4.8 ± 0.10	-
19.	*Acer negundo* L.	7.8 ± 0.32	8.9 ± 0.27	10.7 ± 0.33	**14.1 ± 0.57**	7.4 ± 0.29
20.	*A. platanoides* L.	6.3 ± 0.16	8.5±0.36	**9.6 ± 0.61**	7.1 ± 0.31	6.2 ± 0.26
21.	*A. pseudoplatanus* L.	5.5 ± 0.13	6.2 ± 0.14	**8.6 ± 0.26**	7.6 ± 0.15	5.2 ± 0.12
22.	*A. saccharinum* L.	2.6 ± 0.04	2.7 ± 0.05	3.0 ± 0.08	**7.7 ± 0.21**	5.1 ± 0.14
23.	*Ailanthus altissima* (Mill.) Swingle	4.3 ± 0.13	5.0 ± 0.16	5.7 ± 0.27	**6.8 ± 0.29**	3.9 ± 0.08
24.	*Viburnum opulus* L.	5.9 ± 0.21	6.6 ± 0.34	8.4 ± 0.42	**10.7 ± 0.76**	5.5 ± 0.21
25.	*Symphoricarpos albus* (L.) S. F. Blake	5.8 ± 0.21	6.5 ± 0.27	7.3 ± 0.27	**7.9 ± 0.10**	6.5 ± 0.18
26.	*Forsythia ovata* Nakai	8.0 ± 0.24	7.9 ± 0.31	9.1 ± 0.31	**11.7 ± 0.64**	9.9 ± 0.60
27.	*Ligustrum vulgare* L.	3.3 ± 0.05	3.9 ± 0.09	4.4 ± 0.09	**5.1 ± 0.14**	4.3 ± 0.12
28.	*Syringa vulgaris* L.	6.4 ± 0.20	7.4 ± 0.22	7.5 ± 0.16	**7.8 ± 0.31**	6.3 ± 0.18

T a b l e 2. Multivariate test of significance sigma-restricted parameterization effective hypothesis decomposition.

	Test	Value	F	Effect - df	Error - df	P
Intercept	Wilks	0.001473	2881,227	4	17.00000	0.000000
Season	Wilks	0.013973	10,011	16	52.57348	0.000000

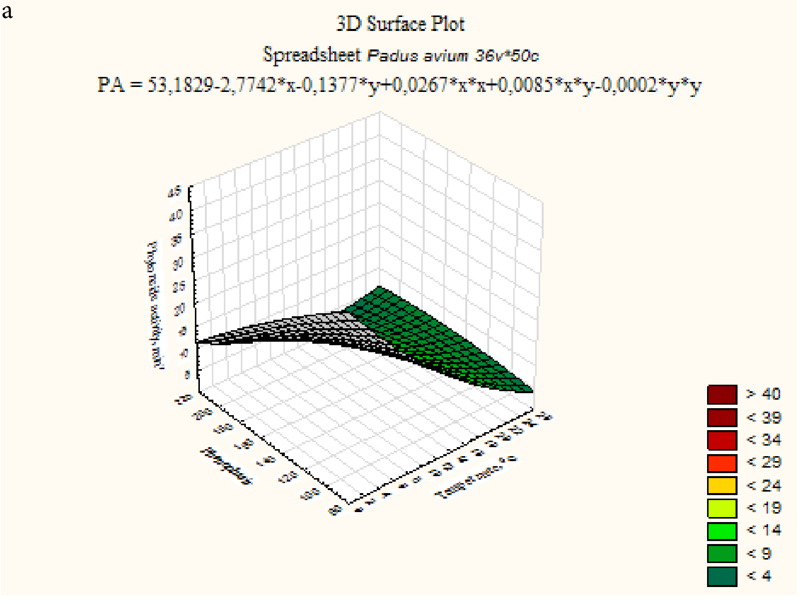
composition of leaves of this species; the amygdalin can be synthesized and emitted outside during the flowering and the fruit ripening period. The hydrocyanic acid cannot be formed in intact

T a b l e 3. Stepwise regression analysis for phytoncide activity of woody plants in the vegetative period of 2011. Negatively correlated variables are made in bold. Statistical significance, p-value: < 0.05 = *; < 0.001 = **; < 0.0001 ***.

Species	**Step 1**	**Step 2**	**Step 3**
Betula pendula	Temp 0.69 ***	Temp **Hum** 0.41 *	Temp Hum Falls 0.61***
Junglans regia	**Falls** 0.76**	**Falls** Temp 0.50*	Hum -
Populus bolleana	Temp 0.63***	Temp Falls 0.34*	-
P. × canadensis	Falls 0.39*	Falls Temp 0.54**	-
P. simonii	Temp 0.90***	Temp Hum 0.33*	-
Salix alba	Temp 0.89***	Temp Hum 0.17*	-
Tilia cordata	Temp 0.82***	Temp Hum	Temp Falls -0.36*
Ulmus pumila	Temp 0.74***	Temp **Hum 0.41***	-
U. laevis	Temp 0.61***	Temp Falls 0.39*	-
Morus alba	Temp 0.85***	Temp Hum 0.56***	
Armeniaca vulgaris	Temp 0.91***	-	-
Malus niedzwetzkyana	Temp 0.64***	Temp Falls 0.50**	-
Padus avium	Falls 1.15***	Falls **Hum 0.76***	Falls **Hum Temp 0.34**
Pyrus communis	**Hum 0.51***	**Hum** Temp 0.41**	**Hum** Temp **Falls 0.39**
Sorbus aucuparia	Temp 0.64***	**Hum 0.55***	-
S. intermedia	Temp 0.75**	**Hum 0.30***	-
Robinia pseudoacacia	Temp 0.90***	Hum 0.19*	-
Aesculus hippocastanum	Temp 0.87***	Falls 0.46***	**Hum 0.21***
Acer negundo	**Hum 0.67**	Temp 0.61***	-
A. platanoides	Temp 0.79***	Hum 0.36*	-
A. pseudoplatanus	Temp 0.95***	**Falls 0.24****	-
A. saccharinum	**Falls 0.59*****	**Hum 0.39***	-
Ailanthus altissima	Temp 0.70***	**Hum 0.55****	
Viburnum opulus	**Hum 0.63**	**Temp 0.62**	-
Symphoricarpos albus	Temp 0.61***	**Falls 0.55****	-
Forsythia ovata	**Falls 0.77**	-	-
Ligustrum vulgare	**Falls 0.57****	Temp 0.41	-
Syringa vulgaris	Temp 0.71***	-	-

leaves because the substrates and enzymes of this reaction are localized in different organelles. During the destruction of tissues, specific glycosidases eliminate sugar, and cyanohydrin as an intermediate product decays to yield ketone or aldehyde and HCN (Roshchina V.V., Roshchina V.D., 2012).

For the species having maximum PA values in the conditions of drought (July), we have stated a strong relation to the air temperature (B > 0.75) – *Populus simonii* Carriér, *Salix alba* L., *Tilia cordata* Mill., *Morus alba* L., *Armeniaca vulgaris* L., *Robinia pseudoacacia* L., *Aesculus hippocastanum* L., *Acer platanoides* L., *A. pseudoplatanus* L. (Table 3). For example, PA of *Tilia cordata* increases with a decrease in humidity ($R^2 = 0.87$). In this group prevail drought-resistant species, which are a



b

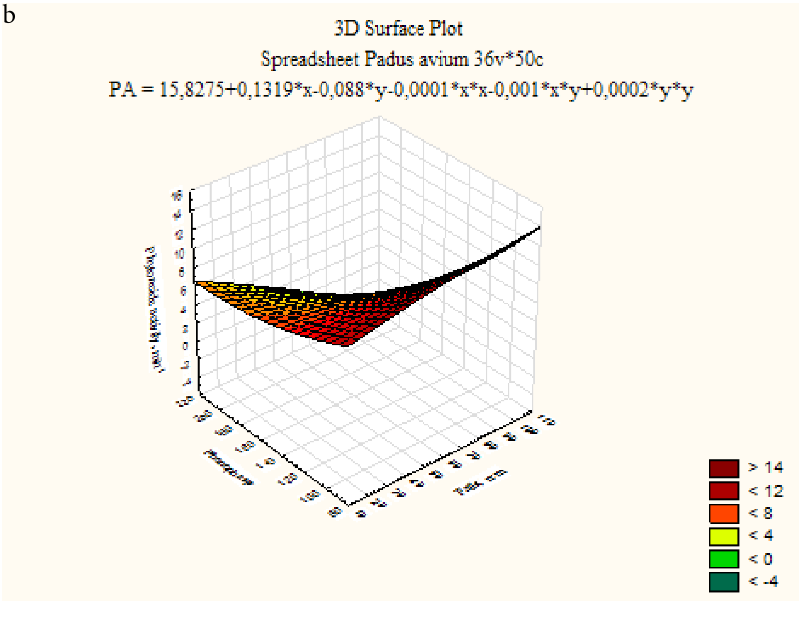


Fig. 2. Seasonal changes in the phytoncide activity of *Padus avium* Mill. depending on the phenophase and air temperature (a), and the phenophase and precipitation (b).

xero-mesophytes and xerophytes. They activate the processes of osmotic regulation, stabilization of cell membranes, detoxification of toxic metabolic products, change hormonal regulation of metabolism and continue the synthesis of secondary metabolites in drought. *Aesculus hippocastanum, Acer platanoides* and *A. pseudoplatanus* are mesophytes and they release a certain amount of BVOC to cool the leaf sheet, and so the effect of high temperature is reduced.

Different mechanisms of increase in PA in August, 2011 are assumed. Drought were determined in August 2011, and 49% of normal precipitation fell in the month, as shown in the Figure 1b. The introduced species and mesophytes indigenous species (*Sorbus aucuparia* L., *Acer negundo* L., *Viburnum opulus* L.), which are poorly adapted to the arid conditions of the Southeast of Ukraine BVOC are used as one of the mechanisms of decreasing the leaf temperature. Highly drought-resistant species *Ulmus pumila* L., *Armeniaca vulgaris* L., *Pyrus communis* L., *Aillanthus altissima* (Mill.) Swingle, *Syringa vulgaris* L. have shown these mechanisms in another way, due to their adaptive reactions to dry conditions. The strong and moderate direct relation to the air temperature has been established for these species.

From the standpoint of plant physiology, mechanisms of action of high temperature on the emission of volatile compounds are not completely revealed. They are of great interest, however, since the regulation of BVOC emission by plants at drought is closely related to global warming. Severe drought reduces the release of monoterpenes, but at the beginning of moisture deficit a flow of monoterpenes grows. In severe drought stomata close, transpiration stops, so BVOC are not emitted any more (Harley et al., 2014). The papers show that at extremely high temperature, one can observe the increased release of monoterpenes, located in cell compartments until the destruction of membranes. On the contrary, monoterpenes, sesquiterpenes and phenols formed under stress are reduced (Kleist et al., 2012; Pag et al., 2013).

Highly drought-resistant species showed the direct strong and moderate regressive relation to the air temperature. In conditions of normal humidity and high temperature, these species have maximal PA, but then it decreases in drought due to stopped transpiration and closed stomata at very low humidity. Most of the species are either indigenous or introduced from North America and China, and are adapted to local hydrothermal conditions. According to Polyakov (2009), the high drought-resistance is typical for the majority of the species from Circumboreal, Atlantic North American and Iran-Turan floristic regions, growing in urban conditions of Donbas. The species from East Asian and Mediterranean floristic regions are significantly less drought-resistant.

Due to the moisture deficit in summer in the south-east of Ukraine, most of the studied species are high and medium drought-resistant. They are widely used in planting in the cities of this territory and adapted to local microclimatic conditions (Polyakov, 2009). The transpiration of non-resistant species is disturbed because of turgor loss; also, there are violations in the synthesis of secondary metabolites, therefore, the phytoncide activity of these species decreases. So, the maximum phytoncide activity of *Aesculus hippocastanum* was noted on July 2011, while the drought was observed in August. However, the specimens of *A. hippocastanum* were affected by a leaf-mining moth. Kleist et al. (2012), Grote et al. (2013) and their colleagues note that the amount of BVOC at high temperature decreased under the biotic stress in mesophytes woody species.

It is necessary to single out the species, for which no regressive relationship between the air humidity and antiprotozoal activity was defined ($B < 0.45$) – *Junglans regia* L., T a b l e 4. Antiprotozoal activity (min^{-1}) of deciduous woody plants over the vegetative period of 2010, all the data is significant at p≤0.05, bold type – antiprotozoal activity peak.

No.	Species	Months				
		May	June	July	August	September
1	*Populus bolleana*	6.5 ± 0.26	5.5 ± 0.10	**7.4 ± 0.25**	7.3 ±0.25	3.9 ± 0.13
2	*P. × canadensis*	5.6 ± 0.18	6.3 ± 0.13	7.5 ± 0.19	**10.6 ± 0.18**	5.2 ± 0.15
3	*Tilia cordata*	14.3 ± 1.51	17.0 ± 0.97	18.7 ± 1.22	**19.5 ± 0.71**	7.0 ± 0.42
4	*Robinia pseudoacacia*	6.0 ± 0.18	7.7 ± 0.46	8.4 ± 0.40	**8.5 ± 0.43**	4.0 ± 0.08
5	*Aesculus hippocastanum*	7.7 ± 0.39	8.8 ± 0.32	11.0 ± 0.39	**13.1 ± 1.0**	7.6 ± 0.42
6	*Acer platanoides*	10.7 ± 0.62	**11.5 ± 0.31**	10.3 ± 0.30	9.0 ± 0.27	7.2 ± 0.30
7	*A. pseudoplatanus*	**8.0 ± 0.32**	7.9 ± 0.14	7.0 ± 0.14	7.4 ± 0.10	6.1 ± 0.15
8	*Fraxinus excelsior*	**6.5 ± 0.17**	5.9 ± 0.06	5.8 ± 0.09	5.1 ± 0.12	4.4 ± 0.04

T a b l e 5. Stepwise regression analysis for phytoncide activity of woody plants in the vegetative period of 2010. Negatively correlated variables are made in bold. Statistical significance, p-value: < 0.05 = *; < 0.001 = **; < 0.0001 ***.

Species	Step 1	Step 2	Step 3
Populus bolleana	Temp 1.95***	Hum 0.79***	Falls 0.74**
P. × canadensis	Temp 1.18***	Falls 0.69**	**Hum 0.46**
Tilia cordata	Temp 1.44***	Hum 1.16**	-
Robinia pseudoacacia	Temp 1.30***	Hum 1.24**	**Falls 0.61**
Aesculus hippocastanum 2010	Temp 1.10**	-	-
Acer platanoides	Hum 1.87**	Temp 0.78*	Falls -1.01*
A. pseudoplatanus	Temp 0.89***	-	-
Fraxinus excelsior	Hum 1.51***	Temp 1.17**	-

Notes: Temp –Temperature, Hum – Humidity, Falls – Falls.

Populus bolleana Lauche, *P. × canadensis* Moench, *P. simonii* Carriére, *Armeniaca vulgaris* L., *Malus niedzwetzkyanna* Dieck, *Acer pseudoplatanus*, *Symphoricarpos albus* L., *Forsythia ovate* Nakai, *Ligustrum vulgare* L. and *Siringa vulgaris* L. (Table 3). The antiprotozoal activity of these species was evenly increasing during the dry period, decreasing in autumn.

The basic data, typically for hydrothermal conditions of the Southeast of Ukraine, is expedient to be compared to that, when a severe drought was observed (Fig. 1a). The precipitation during this vegetative growth of species in August was 5% of the normal amount. Multiple stepwise regression analysis for *Populus bolleana*, *P. × canadensis*, *Tilia cordata*, *Robinia pseudoacacia*, *Aesculus hippocastanum*, *Acer pseudoplatanus, Fraxinus excelsior* showed that the temperature was a major factor, as in the previous year, as shown in the Table 4 and 5. The second important factor is air humidity.

Under the influence of a deep long-lived drought for representatives of the genus Populus (*Populus bolleana, P. × canadensis*), it is stated that meteorological factors have a significant influence on the antiprotozoal activity of leaves. In the case of *P. bolleana*, the most influence is produced by a factor of humidity. For *P.* × *canadensis*, precipitation is more important because it has more moisture like woody plant. This pattern is observed under more favourable conditions (2011).

In 2010, highly drought-resistant species *Tilia cordata, Robinia pseudoacacia* showed a high PA under the conditions of most severe drought and moisture deficit, while mesophytic species revealed a drop in antiprotozoal activity and a strong relation to the air humidity.

The analysis of changes in the antiprotozoal activity of leaves of the studied species revealed the important role of air humidity for PA dynamics. Regressive relationships between the antiprotozoal activity of the studied species and the relative air humidity give a better explanation for the phytoncide activity dynamics under hydrothermal stress. The high and moderate negative coefficients of correlation between PA and air humidity in 2011 were observed for the species having the maximum antiprotozoal action of volatile compounds in the hottest month, that is consistent with the available evidence. So, V.V. Slepyih and other authors note the peak of phytoncide activity in the hottest summer month with low air humidity (Slepyih, 2004; Steinbrecher et al., 2009; Oderbolz et al., 2013).

Thus, air temperature is proved to be a major factor defining the seasonal dynamics of phytoncide activity. Majority of investigating species have maximum phytoncide activity in the phase of second growth of shoots, in the summer. Such a tendency is due to the peculiarity of biological processes of these plants. The antiprotozoal activity of the woody plant species that are poorly adapted to the heat increases under hydrothermal stress, as an adaptation to low humidity and high temperatures of air, but the common activity of plants in areas with drought period at these species are low and in the urbanized conditions, it affects a state of the assimilatory device. The maximum phytoncide activity of high and medium resistant woody plant species occurs in the month when temperature is high, but humidity is normal, as highly phytoncide plants. These species (*Populus simonii, Salix alba, Morus alba, Robinia pseudoacacia, Ulmus pumila, Aillanthus altissima*) activate the preadaptive mechanisms to adverse growth conditions. They are the most perspective woody plants to use in the urbanized territories with an arid climate for improvement of ecological state and normalisation of the atmosphere.

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THE STATUS OF PARENCHYMATOUS ORGANS OF THE CASPIAN SEAL *Phoca caspica* UNDER THE CONDITIONS OF TOXICANT ACCUMULATION

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Abstract

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The toxicological study conducted revealed high concentrations of hydrocarbons and highly toxic heavy metals in the liver and subcutaneous fat of the Caspian seal. The increased toxicant level in the fat, as compared to the liver, pointed to the disorder of organism purification processes, leading to chronic polytoxicosis and disorders of the histological structure of the internals. The studies of the morphofunctional state of the stomach of the Caspian pinnipeds revealed the following disorders: hemorrhages, edemata and necrosis of the mucous membrane, and replacement of glandular tissue with the connective tissue. The study of the small intestine of the seals identified the symptoms of catarrhal desquamatory enteritis. Epithelium dystrophy and desquamation were noted, in particular at the tops of the villi. Different types of colitis (acute, ulcerative, chronic) were found in the large intestine of the seals. Dystrophic and necrotic changes of hepatocytes were identified in the liver tissue, which pointed to the liver cell failure. The nature and extent of pathological changes in the internals and tissues of the studied animals point to the functional depression of the digestive system.

Key words: Caspian seal *Phoca caspica*, hydrocarbons, heavy metals, disorders, negative effect, Caspian sea.

Introduction

The problem of health protection of the marine mammals is becoming more challenging as a result of a dramatic reduction of some species. As about 40% of the species inhabiting the Caspian Sea are endemics, any threat can lead to potentially great losses of its unique biodiversity. One of these species is the Caspian seal or the Caspian phoca (*Phoca caspica,* Gmelin, 1788).

Pollution of the marine environment is sure to create extreme life conditions for marine mammals and fish species having a long life cycle and possessing the ability to accumulate information on the anthropogenic water pollution; as a result, these organisms serve as indicators of the toxic status of marine ecosystems (Attril, Depledge, 1997; Moiseenko, 2009). There are numerous instances when hydrocoles suffer from adverse effects of oil spills in the coastal sea areas (Page et al., 1998; Patin, 2001), discharges of formation waters, drilling fluids and drill cuttings (OSPAR, 2000). Among the main toxic substances that can have an adverse effect on the life of the Caspian seal are hydrocarbons (HC), especially aromatic hydrocarbons (AHC), and such heavy metals (HM) as lead (Pb) and cadmium (Cd). These toxic substances are defined as high-priority toxicants in the process of environmental monitoring and ecosystem impact assessment in many countries of the world. Lead and cadmium are at the top of the toxicant list as per the resolution of the Target Group on Discharges of the UN Economic Commission for Europe. The relative contribution of petroleum hydrocarbons and heavy metals to the overall anthropogenic pressure on the habitats is the highest (Tyutyunnik et al., 2000; Frumin, 2013).

The analysis of the structural and functional state of animals' organs and tissues highlights the impact of environmental factors on the organism; therefore, the objective of the paper was to study the status of tissues of digestive organs of the Caspian seal under the effect of toxicant accumulation.

Material and methods

The biological material was sampled during research field trips to the pre-winter hauling grounds of the seals near Maly Zhemchuzhny island.

The period of regular studies covered 5 years (2011–2015). Throughout this period, samples of 38 seals were collected and analyzed, the seals being of different age and gender. In addition, 70–130 individuals of common kilka (*Clupeonella cultriventis caspia*) were analyzed annually, as this is the main feeding source for the seal. The content of hydrocarbons and their aromatic fraction, lead and cadmium, was determined using common toxicological methods (Guidelines 213/97, 1997; NDI 05.14, 2007).

At the same time, samples of digestive organs (small and large intestine, stomach and liver) of 22 animals of different age and gender were taken for histological analysis. The samples were stored in Bouin fluid and 10% neutral formalin. The material was processed using techniques widely applied in histology (Volkova, Yeletsky, 1989). Histological sections were colored by hematoxylin–eosine and azure-II eosine as per Mallory method.

The pathological changes in the tissues and organs of hydrocoles were diagnosed and assessed in line with the method offered by Lesnikova and Chinareva (1987). Ranging scale was as follows:

- I point – Organism response not leading to its damage.
- II points – Slight damage. Slight vessel hyperemia.
- III points – Medium damage. Vessel hyperemia, perivascular and pericellular edemata, focal hemorrhages.
- IV points – Severe damage. Numerous focal hemorrhages, significant edemata, dystrophy, necrosis of about 30% of the tissues.
- V points – Symptoms of lethal intoxication. Significant damage of the internals under the impact of relevantly low concentrations of toxic substances, approaching chronic lethal concentrations, and almost a complete absence of damage symptoms under high lethal concentrations, but for a short exposure period.

One hundred and twenty-six animals of different age and gender were studied for the presence of parasites. Parasitological studies were conducted in line with the commonly accepted methods (Skryabin, 1928; Delyamure, Skryabin, 1965; Guidelines, 2011).

The parasite organisms were identified by means of guidelines "Trematodes of humans and animals" (Skryabin, 1947–1978), "Ranger of parasites of freshwater fish fauna of the USSR" (1984–1987), and with help of the detailed descriptions of parasites of the Caspian seal presented in the studies conducted earlier (Kurochkin, Zablotsky, 1958; Kurochkin, 1961; Delyamure et al., 1964).

Results and discussion

Morphofunctional characteristics of an organism depend on the status of the environment and food quality. The pollutants are slowly removed from the organs and tissues, and their toxic effect grows in case of their extended impact on the marine mammals even in small concentrations (Cherkashin, 2005). The conducted toxicological study points to the high bioaccumulation capacity of the organs and tissues of the Caspian kilka, which make up to 84% of the food stock for *P. caspica*.

The northern part of the Caspian Sea is known for its oil and gas potential; a large oil-and-gas-producing region is emerging here (Serebryakov, 2013). Petroleum hydrocarbons remain the main pollutants of the North Caspian. The mean long-term concentration (2006–2015) of these toxic substances in the North Caspian water exceeds the maximum allowable concentrations, adopted for fishery-significant water bodies, by more than three times (Popova et al., 2017). Starting from 2011 to 2015, the mean content of petroleum products in the North Caspian ranged significantly – from 3.2 to 7.6 MAC. In the past decade, the concentration of hydrocarbons (HC) in the organs and tissues of ichthyofauna of the Caspian Sea ranges from several dozens to several hundred mcg/kg. The content of these toxicants in the common kilka organism in 2011–2015 varied from 49.1 to 101.8 mg/kg, with the maximum value in 2013 and minimum value in 2013. The aromatic hydrocarbons (AHC) were detected annually, their concentration ranging from 5.9 to 12.1 mg/kg; the maximum was registered in 2012, and the minimum in 2013. It should be noted that the threshold level of aromatic component content in the total amount of HC measuring 1% and adopted as a pollution indicator (Mironov et al., 1990) was exceeded by 5.7–12.9 times.

The results of toxicological studies of the Caspian seal tissues showed, that throughout 2011–2015 the content of HC ranged from 36.4 to 90.3 mg/kg, and the content of AHC varied from 4.0 to 14.3 mg/kg. The aromatic component amounted to 5.0–18.2%. The dynamics of hydrocarbons accumulation was not apparent; the rise in concentrations was observed both in the beginning of the study period (2011 and at the end of it (2015). The mean values of HC and AHC content in the seal liver for the 5-year period of study amounted to 65.9 and 9.7 mg/kg (i.e. 13.3%) respectively; and in the seal subcutaneous tissue, it measured 64.5 and 6.8 mg/kg (11%).

The comparison of individuals of different age revealed higher values of hydrocarbon accumulation (both total and aromatic) in the liver and fat tissues of older seals. As compared to young animals, the increase in adult females and males was 16–37 and 12–19% respectively. The general trend for all the age and gender generations was the fact that hydrocarbons accumulated more intensively in the fat than in the liver tissue (Fig. 1).

The age factor also affected the distribution of AHC: This toxicant concentration grew in compliance with the age of the individuals; the increase in the fat and liver was 120–190% for females and 25–52% for males. The content of aromatic compounds in liver and fat tissues depended on gender: the females (young, farrow, pregnant) accumulated these substances mostly in the subcutaneous fat, while males accumulated the pollutants in the liver (Fig. 2).

In addition to hydrocarbons, highly toxic heavy metals – lead and cadmium – are widely spread pollutants of the North Caspian. There are tough standards for limits of these pollut-

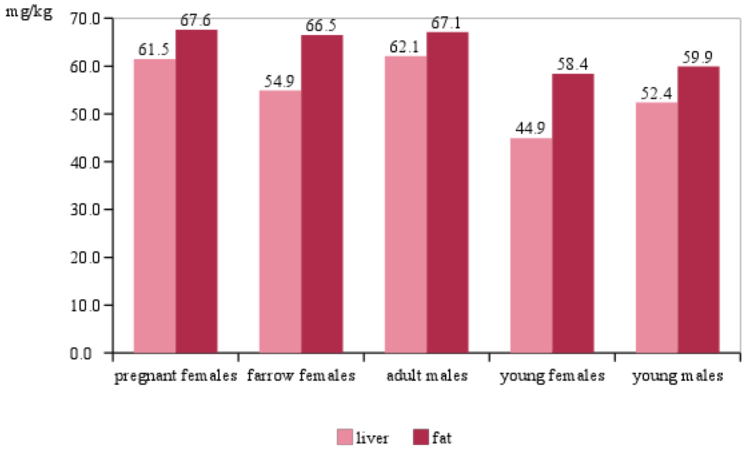

Fig. 1. The content of hydrocarbons in the liver and subcutaneous fat of the seals of different age and gender.

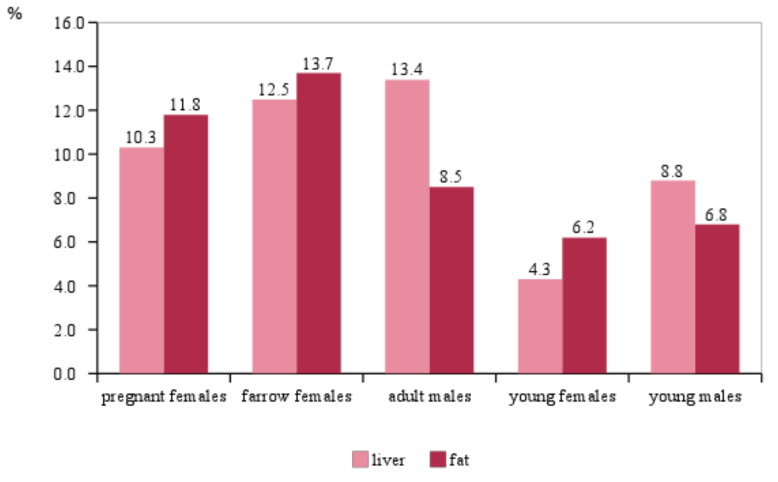

Fig. 2. The content of aromatic hydrocarbons in the liver and subcutaneous fat of the seals of different age and gender.

ants content in fishery-significant water bodies. Their long-term concentration in the North Caspian water (2006–2015) varied slightly and did not exceed the standards. Despite this fact, these toxicants accumulated in the Caspian hydrocoles in quantities that often exceeded the safe content level as per requirements of SanPiN 2.3.2. 1078-01. Thus, the mean long-term content of Pb and Cd in the organism of the common kilka amounted to 3.6 and 0.33

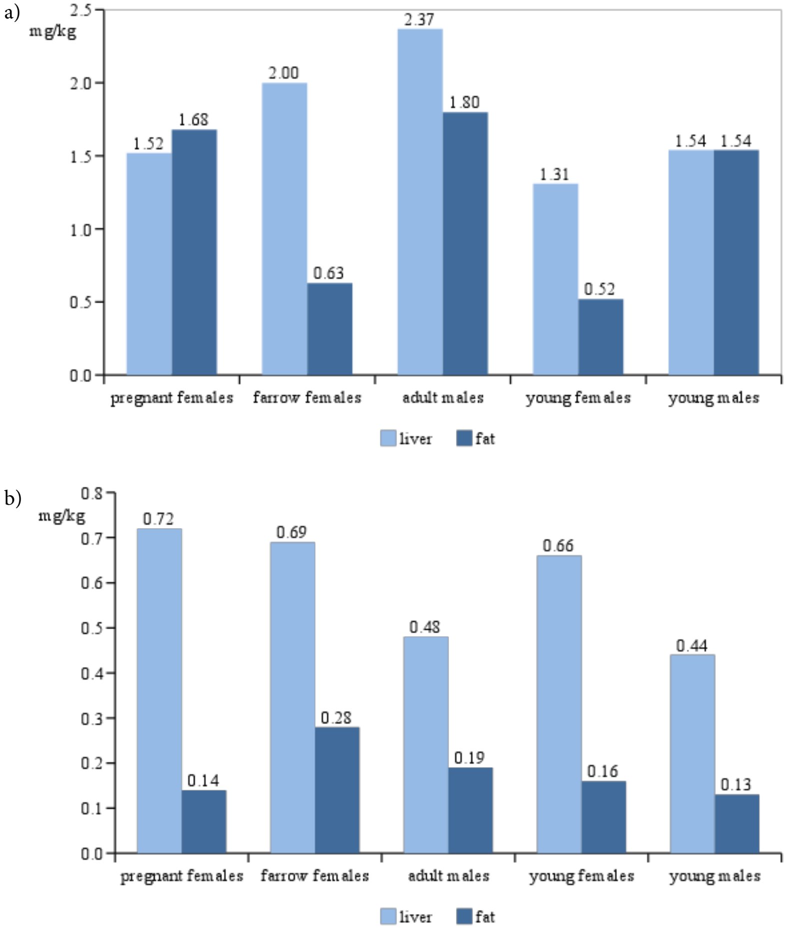

Fig. 3. The content of lead (a) and cadmium (b) in liver and fat tissues of seals of different age and gender.

mg/kg respectively, which exceeded the accepted standards by 3.6 and 1.7 times. The values peaked in 2013. The data on the content of Pb and Cd in the tissues of the Caspian seal in 2011–2015 were of the same order as in the kilka organism, which pointed to stable accumulation. The concentrations in the liver ranged from 1.31 to 2.37 and 0.36 to 0.85 mg/kg, those in the subcutaneous fat varied from 0.47 to 1.93 and 0.13 to 0.30 mg/kg respectively. It should be noted that the standards were exceeded in most cases. Lead accumulation was decreasing from 2011 to 2015, while the accumulation of cadmium peaked in 2013.

The analysis of lead concentration in the liver and subcutaneous fat tissues of the Caspian seals revealed the age-related increase by 16–23% and 10–56% for females and 17–37% and 9–46% for males respectively (Fig. 3). Maximum concentration of lead was revealed in the tissues of adult males, which was obviously conditioned by the ongoing physiological processes accelerating the removal of heavy metals from the organism, such as pupping, lactation and molting, in the organisms of other groups of animals. Cadmium accumulation was higher in females than in males. According to earlier studies, the highest accumulation of this metal is found in lactating females (Zakharova, 2004).

The concentration of cadmium was much higher in liver tissue as compared to subcutaneous fat in all age and gender groups. The distribution of lead content was similar, except for the pregnant females.

In general, the results of toxicological studies pointed to the chronic toxic pressure on the organisms of the animals under study.

The studies of morphofunctional status of the internals made it possible to identify a number of disorders. The histological analysis revealed that the stomach lining of the studied seals was highly hyperemic; it had rough folds and significant regions of epithelial cells exfoliation were noted. The main bulk of the proper mucous plate of the stomach consisted of numerous gastric glands. The lumen of gastric glands was poorly distinguished as a result of the edema of the proper mucous plate. The edges of the gland cells could not be determined as well. The epithelial cells flaked off the basal membrane in 30% of the sampled glands; all the cell content was concentrated in the apicalis. Most of the epithelial cells of the gland bottom had pyknotic nuclei.

Lymphocyte infiltration regions were detected in the proper mucous plate of the stomach in 86.4% of the animals. As a rule, those regions were localized in the upper top part of the mucous membrane.

Of the animals observed, 77.3% developed small hemorrhages in the fibrous loose connective tissue of the proper plate close to the stomach lumen and capillary ruptures with blood entering the gastric pits and eventually the stomach lumen. And 72.7% of the studied animals had necrotic regions in the epithelial layer of the mucous membrane. Significant regions of cirrhosis between the glands, which lead to the replacement of necrotic loci, were observed in 90.9% of the individuals (Fig. 4).

Submucous tissue separated from the mucous membrane by a tough muscle plate consisting of loose connective tissue and included numerous blood vessels of different diameters. The vessels were enlarged and filled with plasma. Then there was a thick muscular coat consisting of three smooth muscle layers.

Thus, according to the study of the histopathological status of the Caspian seal stomach, most samples were characterized by the following significant disorders: edemata of the mucous membrane, hemorrhages, necrosis of the mucous membrane tissues and the replacement of glandular tissue by connective tissue, which points to catarrhal gastritis.

The analysis of the seals' small intestine revealed different height, length and thickness of the intestinal villi. The tops of the villi were enlarged as compared to their bases. Necrotized regions of epithelium were identified at the tops and the sides of the villi in 90.9% of the animals under study. Some of the epithelial cells had their apical parts destroyed. The study also identified regions where epithelial cells were destroyed completely to the basal membrane. The study detected whole epithelial layers separated from the basal membrane.

Limbic cells made up the bulk of epithelium. Among them, in 95.5% of the cases enlarged goblet cells were identified (Fig. 5), at the tops of the villi in particular.

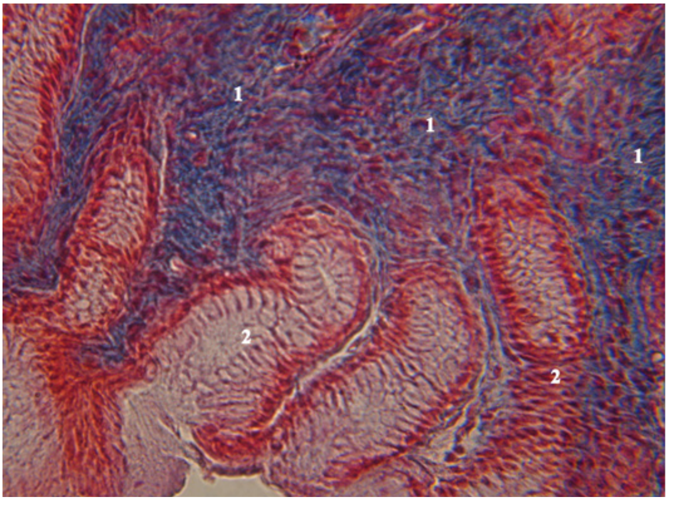

Fig. 4. Mucous membrane of a seal's stomach.
Notes: OK10 OB 40 Mallory coloring. 1. Significant regions of cirrhosis. 2. Gastric glands.

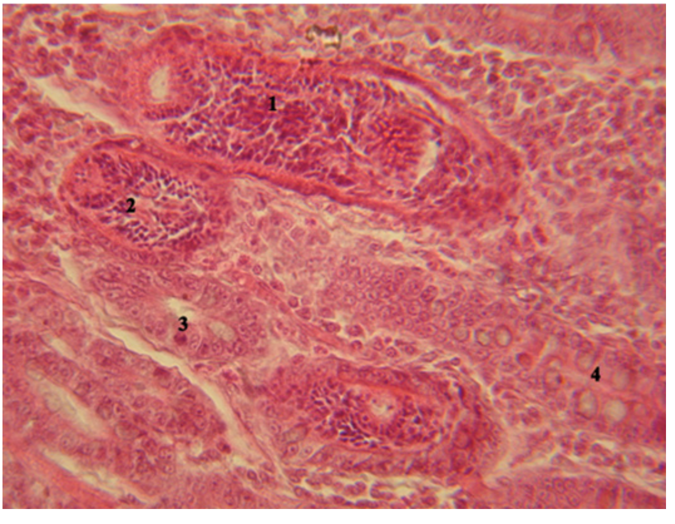

Fig. 5. Small intestine of the Caspian seal.
Notes: OK10 OB90 Hematoxylin – eosine. 1, 2. Bowel worms. 3. Intestinal crypt. 4. Goblet cells.

Limbic cells had fine-grained cytoplasm, a basally located oval nucleus with one or two nucleoli. It was difficult to clearly identify the basal membrane in 81.8% of the studied animals as a result of the edema. Intestinal crypts were lined mainly with poorly differentiated lower-lying cells as compared to epithelial cells of the intestinal villi. Some cells with acidophilic granules (Paneth cells) were identified at the edge of the villi and the crypts. The crypts were filled with mucin. Intraepithelial lymphocytes were permanently present between epithelial cells of the intestine.

The proper plate was made up of fibrous loose connective tissue with high content of lymphocytes and macrophages. The blood capillaries of the villi were unevenly enlarged, in particular at the tops of the villi; small hemorrhages were identified in the connective tissue of the tops of intestinal villi.

In some of the villi tops, the necrosis affected not only the epithelium, but the connective tissue as well. Capillary ruptures were noted at the tops of intestinal villi, which resulted in blood entering the lumen of the intestine. Of the studied seals, 81.8% had developed edemata not only in the epithelium, but also in the underlying connective tissue.

Then, 86.4% of the seals had enlarged limbic epithelium of the sides of intestinal villi, which led to the formation of wide epithelial plates. Invasive species such as *Ciureana badamschini* and *Mesorchis advena* were identified in all tissue specimens (Fig. 5). The prevalence of these invasive species ranged from 80% to 100%. The abundance of the parasites measured a hundred thousand. Maritas were localized in the mucous membrane of the intestine.

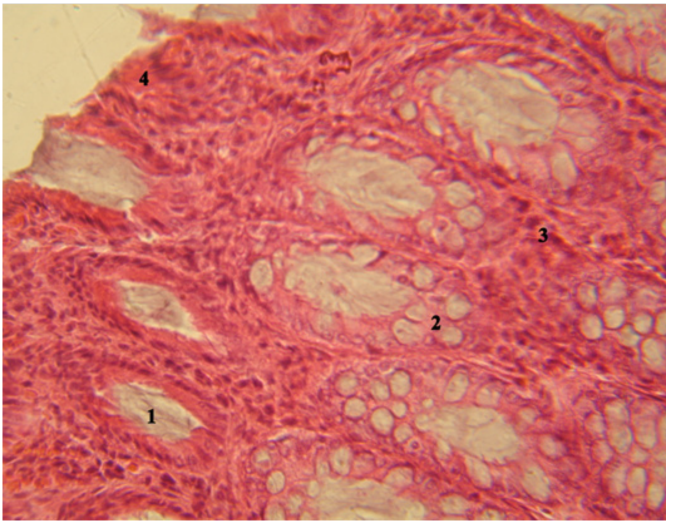

Fig. 6. Large intestine of the Caspian seal.
Notes: OK10 OB90 Hematoxylin – eosine. 1. Intestinal crypt. 2. Goblet cells. 3. Proper plate of the mucous membrane. 4. Blood corpuscles.

In addition to trematodes, *Ciureana badamschini* and *Mesorchis advena,* the organs of the Caspian seals' digestive system were contaminated with helminthes: *Anisakis schupakovi, Pseudamphistomum truncatum, Corinosoma strumosum* and *Eustrongylides excisus.*

The results of parasitological monitoring showed that the mean long-term contamination of the Caspian seal with nematodes *Anisakis schupakovi* was in the range of 91.3±3.2%; roundworms *Eustrongylides excisus* within 5.0±3.8%; proboscis worms *Corinosoma strumosum* in the range 78.1±5.1%; and digenetic trematodes *Pseudamphistomum truncatum* within 68.3±5.2%. The prevalence index made 48.9±12.3, 0.8±0.3, 47.6±7.9 and 2392.5±484.1 parasites per individual respectively.

Parasites not only destroy the tissues mechanically, but they also produce a negative effect on the organism of the host, intoxicating it with metabolism products and breakdown products, which add to the toxic pressure on the organism and leads to deterioration of the organism barrier function (Lysenko, 2009).

Taking into account the impact of exogenous and endogenous toxic substances, it is logical that the intestine of the animals under study developed the symptoms of catarrhal desquamatory enteritis: plethoric and edematous mucous membrane was excessively covered with mucous exudate. 86.4% of the animals developed dystrophy. Epithelium desquamation, in particular at the tops of the villi, was recorded in 59.1% of the cases.

The results of the study of the large intestine showed that its lumen was lined with one-layer columnar limbic epithelium with a large amount of goblet cells. It where 86.4% of the animals had regions of epithelial necrosis (Fig. 6).

The mucous membrane was strongly hyperemic; goblet cells in 90.9% of the animals were enlarged as a result of a large amount of the released secretion. In 77.3% of cases the study identified the crypts with epithelium flaking off the basal membrane and the crypts where epithelium cells were halfway destroyed. In 81.8% of cases, the study recorded the regions of different sizes with the signs of inflammation accompanied by the expansion of the infiltrate to the submucous membrane. Hemorrhages of different sizes were detected in the mucous membrane of the large intestine. These changes are typical of acute colitis.

Some of the individuals had their mucous membrane of the large intestine infiltrated by lymphocytes, neutrophils and eosinophils, the vessels were unevenly enlarged, and there were numerous erosions, which is the symptom of ulcerative colitis.

Some individuals developed chronic colitis, which was characterized by pronounced inflammatory phenomena. Thickening and desquamation of the germinal epithelium were identified. Numerous hemorrhages and erosions of the epithelial layer were noted in the mucous membrane. The study identified the regions of proliferation of the connective tissue, which replaced the regions of the intestinal crypts subject to necrosis close to the lumen in the mucous membrane in the animals under study. Atrophy and sclerosis of the mucous membrane were observed; the connective stroma of the folds and the villi was exposed. Intestinal helminths were identified in histological samples of all the animals.

The study of the Caspian seal intestine showed that the mucous membrane of the intestine was plethoric, edematous and covered with mucous exudate. In particular at the tops of the villi, epithelium dystrophy and desquamation, were observed. The signs mentioned above point to the presence of catarrhal desquamatory enteritis. The histological analysis also revealed intestinal helminths in all of the animals under study. The assessment of the scope of disorders showed that the extent of organs damage was the highest in pregnant females and corresponded on average to 3.8 scores. In descending order, they were followed by farrow females, 3.4 scores; adult males, 3.5 scores and immature males and females, 3.3 scores.

The earlier studies of the intestine of the Black Sea dolphins affected by intoxication identified acute enteritis in the animals. The symptoms were of malignant nature and were the main cause of the animals' death (Solntseva, 2002).

The status of animals' digestive organs primarily depends on the food quality. Long-term small-dose intake of toxic substances with food and water leads to deterioration of the barrier function of the organism and to inability to resist invaders (parasites, viruses, bacteria etc.). Parasites not only destroy the tissues mechanically, but they also produce a toxic effect on the organism of the host, intoxicating it with metabolic products of the living helminths and decay products of the dying ones, and trigger secondary infections (Semenova, 2001; Lysenko, 2002).

In accordance with the research carried out earlier (Semenova, 2001), the identified changes of the digestive organs of the Caspian seals were also similar to disorders emerging in the course of experimental toxic impact on the mammals.

The results of the studies of liver pointed to its exposure to pathologic changes. It should be clarified that under normal conditions of the seals' life, the level of toxicant accumulation in their liver is higher than in subcutaneous fat. It is related to the fact that the liver performs detoxication function, i.e. the processing of toxic harmful substances and their removal from the organism via digestive system. The disorder of liver excretory function leads to the accumulation of toxic substances in the organism, and in the fat tissue in particular. The increased content of a toxicant in the fat, as compared to liver, is a sign of disorder of the liver detoxication function and the pathological impact of the toxicant on the organism. The pathological changes identified in the liver were the congestion of the organ, the disorder of trabecular structure of the liver accompanied by intensive fibrosis and the formation of pseudolobules consisting of proliferating hepatocytes and penetrated with interlayers of connective tissue. Most of the liver cells were enlarged; they had fine-grain cytoplasm and poorly contoured cells. The edges of the cells were poorly distinguished.

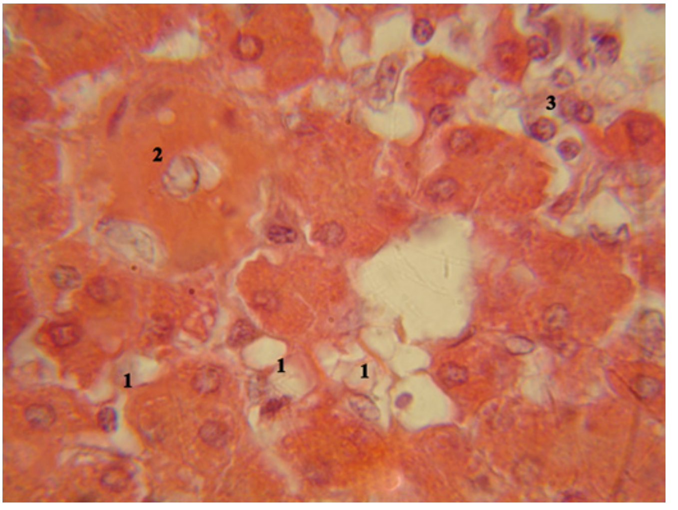

Fig. 7. Liver of the Caspian seal.
Notes: OK10 OB90 Hematoxylin – eosine. 1. Fatty degeneration of the cells. 2. Narrowed lumen of the vessel. 3. Necrosis of hepatocytes and lymphocytic infiltration.

The inflammatory reaction was observed; it was accompanied by the development of necrobiotic and dystrophic processes, the edema of the connective tissue of parenchyma and local lymphocytic infiltration (Fig. 7). The infiltrates of different sizes were generally formed around the vessels.

Hepatocytes were characterized by different dystrophic changes: fatty and albuminous degeneration and degeneration of cells. The above-mentioned disorders were accompanied by the increase of liver cells on average by 1.5 times (16.17±0.73 µm vs. 11.00±0.60 µm). The size of the liver cells on average made 14.10±0.38 µm. No clear edges of liver acini could be observed as a result of the extensive edema of the organ, and the edges of hepatic turbules were vague.

The liver is known to take an active part in homeostasis dynamics, as it occupies the central place in the regulation of the metabolic process and is a link between the portal and the general blood circulation system. Maintaining the constancy of the internal milieu, the liver is involved in detoxication of xenobiotics that enter the blood with digested substances (Ezhkova, 2006). The toxic substances have an adverse effect on the structural elements of the liver, which are in primary contact with the portal circulation (Babanin et al., 2009).

Of the studied animals, 45.5% had small and large necrotic regions leading to the destructive changes of the liver parenchyma, the regions of active regeneration and proliferation of the cells, especially in the connective tissue around small and large vessels of the liver (fibrosis). The lobular structure of the organ was damaged in 95.5% of the studied seals as a result of proliferative, inflammatory and destructive changes of the liver tissue. Of the animals, 72.7% had different-sized hemorrhages in the liver parenchyma.

Hepatocyte polymorphism was registered in 95.5% of cases; as a rule, it leads to the functional disorder of the liver cells as a result of uneven biosynthetic activity.

The nuclei of hepatocytes were polymorphic. The nucleus of the liver tissue cells varied within a wide range: from 3.85±0.22 to 6.16±0.50 μm.

About 20% of the cells had small dark pyknotic nuclei and 60% of the cells had large light round-shaped nuclei with heterochromatin in the periphery. Akaryotic cells were also identified. In most cases the nucleus of hepatocytes was located off center as a result of dystrophic changes. The study revealed swelling of the cells and the presence of small granules of hemosiderin.

In general, the following disorders of the liver tissue of the analyzed seals were identified: inflammatory reactions, accompanied by the development of necrobiotic and dystrophic changes, edemata of the connective tissue and the parenchyma; lymphocytic infiltration as well as active proliferation of the connective tissue around the small and large vessels of the liver. The dystrophic and necrotic changes of hepatocytes lead to liver cell failure. The conducted histological study of the Caspian seal liver confirms that this organ experiences serious pressure. Similar changes were identified earlier in Black Sea dolphins affected by intoxication: dystrophic and necrotic changes of hepatocytes lead to the emergence of liver cell failure diagnosed as cirrhosis (Solntseva, 2002).

The distribution of the average score of the assessment of histopathological status of this organ was similar to that of the intestine: pregnant females, 3.75 scores; farrow females, 3.6 scores; males, 3.6 scores and immature males and females, 3.5 scores.

Conclusion

The results of toxicological studies of the Caspian seals revealed a large amount of aromatic hydrocarbons, lead and cadmium, which accumulated in their liver and the fatty tissue. The allowable level of safe content of these toxic substances was exceeded in most of the samples. The extent of toxicant accumulation depended on the age and gender of the animals.

Morphofunctional studies revealed pathological changes of stomach, small and large intestine and liver in a large amount of seals. The nature of disorder development in the organs and tissues of the seals pointed to chronic intoxication, which is logical with account of the identified high level of toxicant accumulation. The nature of pathological disorders in case of intoxication follows the pattern that the death of an animal as a result of acute intoxication is not accompanied by significant histopathological changes, which do not occur during a short time period. On the contrary, the long-term effect of a toxic substance even in small amounts, which does not lead to the death of the animal, always leads to obvious pathological changes of the internals.

The results of the study show that pathological processes depended on the structural and functional characteristics of the organs. For instance, the internals of the mammals during pregnancy experience additional functional load; therefore, it is logical that the extent of pathological changes in pregnant females was higher than in immature individuals. The most characteristic feature of the negative processes was the disorder of blood microcirculation in the organs. The physiological status of the Caspian seals was burdened by the presence of parasites and therefore by parasitogenic intoxication.

Thus the materials of toxicological, histological and parasitological studies pointed to the depression of the function of digestive system of the studied individuals of the Caspian seals as the pollutants accumulated in their organism.

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SPATIOTEMPORAL BIOACCUMULATION OF LEAD, CADMIUM, ZINC AND COPPER METALS IN LETTUCE SEA *Ulva lactuca* HARVEST IN TWO ALGERIAN WEST COASTS

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Abstract

Abi-Ayad L., Ghezlaoui S.-M. B.-D., Belkhouche N., Aguado J.M.: Spatiotemporal bioaccumulation of lead, cadmium, zinc and copper metals in Lettuce Sea *Ulva lactuca* harvest in two Algerian west coasts. Ekológia (Bratislava), Vol. 37, No. 3, p. 243–258, 2018.

This work brings an evaluation of the quality of littoral zone of Algerian in two neighbouring port coasts, namely, Honaine and Beni Saf, chosen as significant discharge sites. This was followed by a comparison of the state of these coasts with those of the Mediterranean coastal areas. The study was conducted in all seasons in the year 2011−2012 by measuring the hydrological physico-chemical parameters (pH, temperature, turbidity and salinity) and using sea lettuce *Ulva lactuca* as significant 'biomarker of the quantity of metal contaminants (Cd, Pb, Cu and Zn)'. Harvesting of *Ulva* and the seawater samples were performed in each season in three stations, characterised by discharges of waste and industrial water and saline discharges from the recent installation of desalination in Honaine. The metal concentrations in seawater showed significant variations between stations and the harvest season, resulting in the appearance of pollution of Cd, Pb, Cu and Zn. Also this result was manifested in *Ulva* in the station S1 (Beni Saf) and S2 (Honaine-beach) with the exception of copper. These results have exceeded tolerable international standards.

Key words: pollution, bio-indicator, metal, algae, Algeria.

Introduction

In recent years, the dispersion of metal contaminants in Mediterranean areas (western Algeria) is constantly evolving (Taleb, Boutiba, 2007). This phenomenon increases through the increase in harbours' pollution of urban and industrial (oil waste) origin (Pastor et al., 1994).

At present, the marine heritage protection presents a huge challenge for the industrial and scientific communities on both the economical and ecological plans.

The Algerian coast encompasses a wide range of habitats and marine biodiversity, that said, it is considered amongst the highest in the Mediterranean, bringing together the marine species of flora and fauna such as green algae (*Ulva lactuca*, *U. fasciatus* and *Enteromorpha linza*) and red algae (*Corallina officinalis* and *Polygavernosa dentata*). They have the distinction of establishing the balance of the aquatic ecosystem and are good indicators of environmentally health; it is also the case of the brown seaweed *Cystoseira*, which was used in the control of the arsenic, chromium, cadmium and cobalt in the Syrian coast (Nakhlé, 2003). The role of algae in structuring communities of the rocky substrates is well known.

The habitat of these species is characterised by inputs of the pollutants of the agglomerations. This is, in the Algerian coast, that research on these species that are rare and limited to the prospections. For this, we have undertaken eco-biological studies on a particular type of seaweed *Ulva* in the North Shore (Beni Saf, Honaine, etc.), based on its distribution and exposure to pollution to heavy metals.

We found that the species is highly vulnerable to metal contaminants according to the results of previous work (Munda, Hudnik, 1991). The deposit and bioaccumulation of heavy metals in algae is very observable. This has been demonstrated in numerous studies in various Mediterranean regions **(**Bryan, Hummestrone, 1973). That said, the choice focused on these algae is related to their richness in vitamins and trace elements and have therapeutic characteristics indispensable to man, which is necessary to protect them.

These algae were used a long time ago, as part of the traditional diet of coastal communities, but they are part until today in many countries. Their nutrition is made by marine plants, nearly a 3,589,729 t; algae are used for obtaining original chemicals (phycocolloids) that are capable of gelling or thickening aqueous solutions (3.28322 million t). Both these uses have grown steadily since the beginning of the century and, currently, require more than 6,873,949 t of marine plants (fresh weight) per year or 90% of total production (7 637 721 t) in 1994 (Perez, 1997).

Furthermore, this allowed the classification of marine green chlorophylliens in Europe, of order food of which were took, *Fucus vesiculosus*, *Himanthalia elongata* (Sea Bean or seafood spaghetti), *Ascophyllum nodosum* and *Undaria pinnatifida* (sea fern) are in the first position; *Palmaria palmata*, Laver, *Chondrus crispus* (lichen) and *Verrucosus gracilaria* (ogo-nori) are in the second position; the lettuce *Ulva lactuca* seas and *Enteromorpha* sp. are in the third position and *Spirulina* sp. (spirulina) is in the fourth position (Perez, 1997)**.** The recent interest on these *Ulva* is very interesting; given their beneficial virtues, dietetic food is sold in the market in various forms, dried leaves, glitter and granules in powder, whose residents gather around 40–45 t fresh *U. lactuca* (32 t), *Enteromorpha* sp. (1 t) and so on. Still widely consumed in East Asia and particularly in Japan, China and Korea, their use remains limited in Europe, that said, the first attempts to introduce the marine plants in the Western diet actually date from the fifteenth century. In time, they had the aim to soften the famines that struck episodically the coastal populations (Munda, Hudnik, 1991).

In the recent years, the consumption of food plants made a new appearance in the European zone, such as France, Belgium, and Germany. She corresponds at the request of the immigrant Asian colonies, a gastronome, seeking diversity and the people wishing to guard against cardiovascular diseases, a diet low in fat. Much of this demand is met by imports from the Far East. In the United States, aquatic plants are mainly used as ingredients, spices or seasoning, the control of which is necessary to care, relating only to heavy metals and radioactivity levels. Japan has no standards for these productions but very demanding for imported marine plants (Perez, 1997)

The importance of the nutritional value of algae, and some interest on these health benefits arouse recently. The time has come to take stock of the issue.

It is in this context that the protection of aquatic chlorophylls remains essential to preserve the trophic balance of marine ecosystems. In addition, green algae are an excellent source of fibre, minerals and phytonutrients (MacArtain et al., 2007). They are safe for health, although they have to pay attention to certain varieties because of their high content of sodium, iodine and heavy metals (Cheggour et al., 2001). In addition, our concern has become major, facing the bioaccumulation of toxic metals in algae, including Pb, Cu, Cd, Zn and so on, which can lead to their disappearance over the years. The bioaccumulation of toxic metals impacts on marine heritage and causes deterioration of fish and shellfish production, thereby reducing fishing activities that are of economic interest to many countries.

The coastal region of Beni Saf is located on the northwest coast of Algeria, 67 km from the city of Tlemcen (see Fig. 1). Then the Coast of Honaine is halfway between Ghazaouet and Beni Saf. The city of Beni Saf, populated by 42,000 habitants (Leynaud, 1968), is marked by beaches that attract a considerable flow of summer visitors. The port area that was the second fishing port with an average production of 5000 t/year (W.H.O, 1987) today demonstrated a true fall, to the point of some fishes (red grouper, etc.) have become rare. This area includes industrial activities (cement) and maritime traffic. Nevertheless, the area of Honaine (Fig. 1), populated by 5,408 habitants (Leynaud, 1968), reveals an urban and artisanal fishing activities, which is moderately developed compared to Beni Saf, and has just been equipped by the desalination plant. This can cause a potential pollution by saline discharges. The presence of toxic metals from different discharges may increase the degradation of these areas (Taleb, Boutiba, 2007).

The aim of the present work is to carry out a comparative study on the nature and the level of pollution of the two port areas, Beni Saf and Honaine. This will be carried out according to the spatial and temporal assessment of the quality of seawater and bioaccumulation of toxic metals in green algae *U. lactuca*. These toxic metals are Pb, Cd, Cu and Zn, which come from different discharges in the middle. And those to determine the possible transfer of pollution between the areas had taken into consideration that may prejudice for sea lettuce.

Material and methods

The sea lettuce *U. lactuca* was seasonally collected during the period 2011–2012, at the stations shown in Fig. 1.The choice of stations (S) was based on the presence of bio-indicators (*Ulva*) in the vicinity of wastewater effluents (collectors, C), in order to assess their impact on the receiving marine environment to determine the bioaccumulation threshold of metallic pollutants in the species.

The description and nature of wastewater outfalls are summarised as follows:

- - C1 (Beni Saf): Collector receiving a mixture of urban and industrial wastewater (cement plant, shipping traffic and fishing);

- C2 (Honaine; beach): Collector receiving a mixture of urban wastewater from the village of Ouled Youcef;
- C3 (Honaine, port): Collector receiving a mixture of wastewater (artisanal fisheries).

Sampling stations

The sampling stations are as follows:
- S1: the beach and port of Beni Saf, next to collector C1;
- S2:the beach of Honaine Bay, next to collector C2;
- S3:the port of Honaine Bay, next to collector C3.

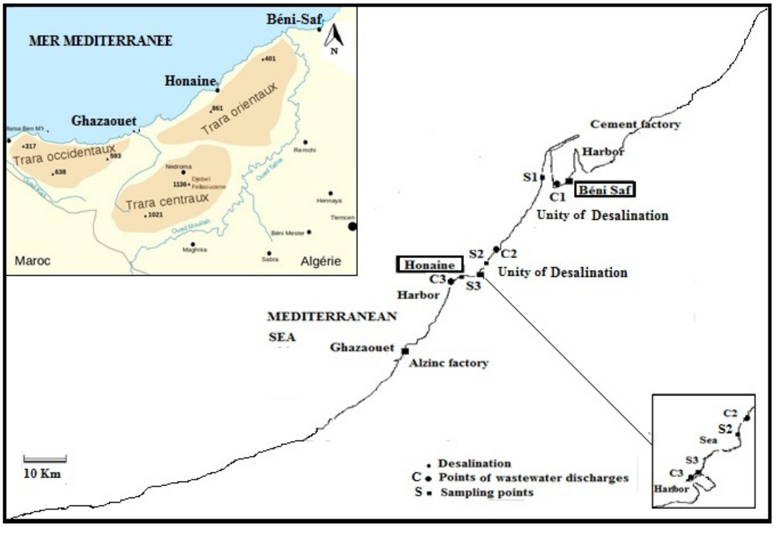

Fig.1. Localisation of sampling sites of sea lettuce along the coasts of Beni Saf and Honaine.

Sample collection and sampling

Samples of seawater and *Ulva* were collected at the following three sampling points: first (01) sampling point is on the separating line between the beach of Beni Saf and its harbour (S1), second and third (02) sampling points are in the area of Honaine, one in the vicinity of the beach (S2) and the other in the harbour (S3). Marine water samples were collected during the period 2011–2012, according to Aminot and Chaussepied protocol (1983). Measurements of some physicochemical factors, such as pH, electrical conductivity, air–water temperature and salinity, were made in situ.

Ulva

Samples of green algae were harvested by hand before being transported to the laboratory in sachets, rinsed with water, ultra-filtered (Millipore) to remove the external impurities and then dried in air. For each sample, we also weighed 1 g of previously ground seaweed and filtered using a sieve (63 µm in diameter). They were placed in Teflon beakers, in which we added 5 ml of 60% of perchloric acid, $HClO_4$, and we left the sample for 1 h at 80 °C on a hot plate under a host. After almost total evaporation, we added, 3 ml of HCl (hydrochloric acid) and 1 ml HNO_3 (nitric acid) to water region. The reaction is always carried out hot at 80 °C to remove all the solid fractions. When all the solid fractions have disappeared, we again evaporated the excess acid. Finally, we introduced 5 ml of doubly distilled water to solubilise the metals (the duration of this step is 2 h at 80 °C). The rest was the adjusted at 20 ml of solution bidistilled, filtered using a filter paper and then stored in boxes in a refrigerator. At the end, the digests are led to the assay for quantification of metals by the spectrophotometric atomic absorption.

Analytics instruments

Sea water: The levels of metals, such as Pb, Cu, Cd and Zn, in seawater was determined using the Aurora Trace AI 1200 – Atomic Absorption Spectrometer supplied with an acetylene torch (Laboratory of Alzinc plant, Ghazaouet). Some physico-chemical characteristics of seawater, such as the conductivity, were determined by a Tetracon 325 conductimeter, whilst pH measurements were made using a Box 389 type pH meter, and the turbidity was measured with a Hach 2100 turbid meter.

Sea Lettuce: The levels of Pb, Cu, Cd and Zn in Ulva samples was determined using the Perkin Elmer 4110 Atomic Absorption model ZL (THGA), in (Seville-Spain).

Analytic performances

The limits of detection (LODs) of heavy metals, such as Pb, Cu, Cd and Zn, for the dosage of seawater samples were determined by Flame Atomic Absorption Spectrometry and assayed in ppm (Table 1).

Limits of detection

The LODs were calculated relative to the standard deviation and reported to the arithmetic mean value. They are given in Tables 1 and 2, respectively, for seawater and *Ulva*.

T a b l e 1. Limits of detection of seawater by Flame Atomic Absorption Spectrometry.

	Cd	**Cu**	**Pb**	**Zn**
LOD (ppm)	0.03	0.05	0.10	0.05

T a b l e 2. Limits of detection of *Ulva* by Flame Atomic Absorption Spectrometry.

	Cd	**Cu**	**Pb**	**Zn**
LOD (ppb)	0.05	0.60	0.30	2

Precision

The accuracy of measurements was evaluated based on the results of certified assayed samples from the Chemical and Environmental Engineering Department for Ulva in Seville (Spain).

Statistical treatment

The statistical analysis of the data was performed using the software STATISTICA (Statsoft Version 6.1.478.0) for calculating the two-factor analysis of variance (ANOVA) (sites, seasons), on seasonal concentrations of heavy metals in *Ulva* (mg/kg dry weight). Data are presented as the mean ± standard error. ANOVA was used to compare means of concentrations of heavy metals between stations; when ANOVA was significant ($p < 0.05$), post-hoc comparison of means was performed using Duncan's test. Statistical analysis was performed using the software STATISTICA (Statsoft STATISTICA version 6.1.478.0).

The horizontal line in each figure shows the average value of references for each metal element by Food and Agriculture Organization of the United Nations F.A.O (1994).

Bioclimatic study

The two fundamental climatic factors, namely, temperature and precipitation, were taken into consideration. These factors affect the state of the marine biotope, and particularly algae, such as *Ulva* (Poggi, 1990). Rainfall affects the quality of sea water, particularly the increase or decrease in water intakes (minerals), water regeneration and ecological phenomena that can take place. In coastal environments, some industrial discharges and stormwater lead to pH change, which in this case turns out to be a pollution index. However, this change remains much localised both in time and in space, because of the buffering capacity of sea water (Aminot, Chausssepied, 1983). On the other hand, the temperature of water plays a critical role in the functioning of coastal ecosystems, which have significant ecological repercussions (Leynaud, 1968). Water temperature acts on the density, viscosity, gas solubility in water, dissociation of dissolved salts as well as the chemical and biochemical reactions and development and growth of living organisms in water, particularly microorganisms (Leynaud, 1968).

Northern Algeria has a Mediterranean climate, which is characterised by hot, dry summers and cool, wet winters. Therefore, two climatic parameters, that is, temperature and rainfall, were considered in order to determine the climate in the areas under study, namely, Beni Saf and Honaine.

The climatic factors were assessed based on the data from Beni Saf and Honaine weather stations. The data were collected for a period of 10 years (2003–2012). The obtained results were used to plot the ombrothermic diagram (Bagnouls, Gaussen, 1953) (Figs 2a,b). From there, it was found that the region of Honaine has a Mediterranean climate with an average annual rainfall of about 350–400 mm. The wettest period extends from November to April with a maximum of 80%. This area has around 20 days of mist. In winter, the average temperature oscillates around 10°C, with a minimum of 6 °C. There is neither frost nor any significant humidity in the air, because of the influence of the sea. By cons, in summer, the average annual temperatures oscillate around 26 °C. East-Northeast and West-Southwest winds prevail in this area (W.H.O, 1987).

The climate in Beni Saf is similar to that of Honaine. The average winter temperature hovers around 15 °C, with a minimum of 8 °C. The average summer annual temperatures oscillate around 26 °C, with a maximum of 40 °C. Calculations show that Emberger's pluviothermic ratio (Q) in the area of Beni Saf is 58.12, whilst that in Honaine is 40.41. Consequently, the climate prevailing in the two areas is semi-arid thermotype, which is characteristic of the climate on the Mediterranean coast.

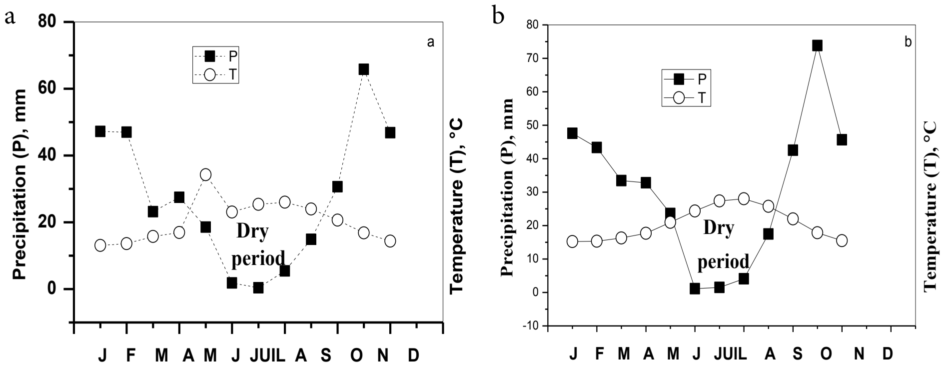

Fig. 2. Ombrothermic diagram of Bagnoul and Gaussen: (a) area of Beni Saf; (b) area of Honaine.

Results and discussion

Sea water features on the coasts of the towns of Beni Saf and Honaine, during the period 2011–2012, are given for the three stations in Table 3.

T a b l e 3. Average characteristics of seawater in the towns of Beni Saf and Honaine, during the period (2011–2012), in all three stations, S1, S2 and S3. The results are expressed as mean ± SE, limit values are in brackets (SE: standard errors).

Stations	pH	Salinity (%)	Conductivity (μS/cm)	T_{Eau} (°C)	NTH (turbidity) (mg/l)
S1	7.13–7.34 7.2 ± 0.09	29.8–37.1 32.23 ± 3.44	46.1–55.7 49.3 ± 4.54	26–24.2 25.4 ± 0.84	0.301–0.557 0.386 ± 0.01
S2	7.25–8.11 7.54 ± 0.33	25–37 29 ± 0.47	50–55.7 51.9 ± 2.68	24.3–29 25.86 ± 2.21	0.203–0.854 0.42 ± 0.025
S3	7.33–8.03 7.56 ± 0.27	36.3–37.1 36.57 ± 0.37	54.8–55.9 55.17 ± 0.51	24.4–25 24.6 ± 0.28	0.143–0.383 0.223 ± 0.009

The physicochemical parameters of seawater recorded during the four seasons provide information about the status of the quality of marine water in the coastal areas of Beni Saf and Honaine.

The observed values indicate that the pH is more or less neutral in the three stations, both in wet and dry seasons. Indeed, the average pH value in both stations (S1 and S3), which receive urban and industrial discharges, is 7.38. This is less than 8, which indicates a slight acidic environment. However, this pH value remains in the recommended Algerian Standards in the case of discharges in the receiving environment (J.O.R.A, 2006).

Turbidity measurement in the three study sites showed different values, which are less than 5. This is in good agreement with the standards (O.I.E, 2009). These results were predictable, as the expertise is found to be consistent with clear surface waters. The annual salinity at the three stations ranges from 29 to 36.57%. These values are within the standard range, which limits the concentrations between 35 and 39% (Huppatzet, 1987). The salinity in closed or isolated seas may be different from that in the great oceans. The lowest average value was recorded at station S2, which is located near collector C2 (beach of Honaine). In addition, the salinity may change during the year, depending on the season. Seawater conductivity is subject to significant variations, depending on temperature and salinity. The obtained conductivities range from 49.3 to 55.17 μs cm^{-1}. This last value was found in station S3, next to collector C3 (wastewater from craft activities). However, these results remain within the standards, as the electrical conductivity extends between 40 and 53 μs cm^{-1}, at the temperature of 25 °C (Marcet, 1919).

Temperature plays a role in the phenomenon of photosynthesis, which is responsible for the species multiplication (algae). Temperature is very important for the solubility of salts, and especially of gases. It also influences the pH. The median value, between 7 and 25 °C, corresponds to a neutral solution (De Villers et al., 2005). Temperature also allows correcting the analysis parameters because their values depend on it (conductivity). Furthermore, by highlighting the contrasts of water temperature in a medium, it is possible to obtain information on the source and the flow of water (Rodier, 1984). The temperatures of seawater, in the three stations, vary between 24.60 and 25.86 °C. These ambient temperatures, which are in agreement with the Algerian discharge standards (J.O.R.A, 2006) correspond to the meteorological conditions at the moment of sampling.

Metal contents in seawater

Levels of heavy metals in seawater are calculated for the three stations and presented in Table 4.

T a b l e 4. Variations in heavy metals concentrations (mg/kg) of seawater in the littoral of Beni Saf and Honaine harbour, during the period (2011–2012) in all three stations S1, S2 and S3. The results are expressed as mean ± SE, limit values are in brackets (SE: standard errors).

	Cd	**Pb**	**Cu**	**Zn**
S1	0.071–0.86 0.33 ± 0.03	0.49–0.65 0.54 ± 0.01	0.025–0.58 0.21 ± 0.02	0–4.25 1.42 ± 0.16
S2	0.022–0.25 0.098 ± 0.01	0.016–0.69 0.24 ± 0.02	0.058–0.083 0.066 ± 0.01	0–0.35 0.12 ± 0.01
S3	0.056–0.11 0.074 ± 0.001	0.35–0.70 0.47 ± 0.01	0.079–0.088 0.082 ± 0.01	0–7.67 2.56 ± 0.30

Cadmium
The observed seasonal concentrations reveal significant levels of cadmium in the three stations. The highest content was found to be equal to 0.86 ppm in the season of autumn at station S1 in the coastal area of Beni Saf. The average annual level of cadmium was 0.33 ppm. This is alarming with regard to the quality of the environment, because cadmium content exceeds the standards of the Mediterranean coastal areas, recommended by FAO, which suggests a minimum level equal to 0.01×10^{-3} ppm (FAO, 1994) (Martin, Whitfield, 1983). This is due to urban and industrial waste (cement plant, shipping and fishing) that are discharged by collector C1, which is located near station S1. A similar result was found on the Atlantic coast of southern Spain (Usero et al., 2003). Indeed, the recorded cadmium levels remain tolerable compared to the discharge standards in a receiving environment, as defined by the Algerian regulations (contents of the order of 3 mg/l).

Lead
Seasonal evaluation of lead in seawater indicates very high levels in the three stations throughout the year. The highest value, that is 0.7 ppm, was observed in station S3 (port of Honaine), in the spring season, whilst the annual average content is 0.54 ppm. This figure is much higher than 0.03×10^{-3} ppm, which is the threshold required by the FAO (Martin, Whitfield, 1983), and 0.5 ppm, which is the value requested by the Algerian regulations (J.O.R.A, 2006). Regarding the annual variations of lead, the content at station S1 exceeds the Algerian discharge standards in a receiving environment. Therefore, it is easy to note that the area of Beni Saf (S1) is lead contaminated. The hypothesis of lead contamination resulting from discharges at collector C1 remains valid, just like before. These results are in good agreement with those found in previous works (Usero et al., 2003).

Copper
Seasonal copper levels were found at values that exceed the standards of the Mediterranean coastal waters (FAO); they were above the threshold limit of 0.001 ppm (Martin, Whitfield, 1983) in all three stations. Indeed, an annual average content of 0.21 ppm was found at station S1. Copper pollution is probably due to discharges at collector C1 (Usero et al., 2003).

Previous works related to the presence of copper dispersed along the Atlantic coast of southern Spain showed similar findings. On the other hand, the annual average remains below the Algerian discharge standards in the receiving environment, where the limit value is 0.5 ppm (Usero et al., 2003).

Zinc
Zinc concentrations were high in the three stations during all seasons, except in summer. They were found much higher than the threshold limit, which is 2.5×10^{-3}ppm, as defined by FAO (Martin, Whitfield, 1983). In autumn, a significant value equal to 7.67 ppm was recorded at station S3 (port of Honaine). However, the annual average content was 2.56 ppm. Station S1 presented a zinc peak in winter, with a concentration equal to 4.25 ppm. This reflects the pollution degree in the port area of Beni Saf, because of urban and industrial discharges from collector C1. However, the contamination of the port area of Honaine (S3) is due to discharges from collector C3, which probably receives zinc effluents from the Zinc Production Plant (Al-Zinc). This finding about pollution is similar to that given previously, concerning seawater along the Atlantic coast of southern Spain (Usero et al., 2003). Compared to the Algerian standards, which define a threshold limit of 0.5 ppm, the pollution situation is still maintained (J.O.R.A, 2006).

In conclusion, the gradient of annual accumulation of heavy metals in seawater in the three stations is as follows: Zn > Pb > Cd > Cu.

Contents of heavy metals in Ulva

The heavy metal contents in the *Ulva* are calculated for the three stations and presented in Table 5.

The concentrations of Cd and Zn, recorded in Table 5, are significant compared to those found in stations S1, S2, and S3 ($p<0.05$). These concentrations are still important for Cd, Pb

T a b l e 5. Variations in heavy metals concentrations (mg/kg; dry weight) of sea lettuce in the littoral zone of Beni Saf and Honaine harbour, during the period 2011–2012, in all three stations S1, S2 and S3. The results are expressed as mean ± SE, limit values are in brackets (SE: standard errors).

	Cd	**Pb**	**Cu**	**Zn**
S1	0.12–0.73 0.36 ± 0.31	0.62–0.91 0.62 ± 0.26	0.02–0.92 0.54 ± 0.67	5–60.64 27.81 ± 28
S2	0.24–0.66 0.39 ± 0.18	0.02–0.71 0.41 ± 0.29	4.3–5.6 4.85 ± 0.98	35.12–104 29.52 ± 30
S3	0.14–0.25 0.15 ± 0.08	0.03–0.81 0.36 ± 0.34	1.4–3.4 2.33 ± 1.36	2–36 12.99 ± 13

and Zn during different seasons. The effect of seasons and stations was proven by the significant result obtained for Pb only ($p<0.05$); however, no significant difference was observed between the stations and seasons ($p<0.001$). The combined effect of stations and seasons remained significant only for lead.

The concentrations of metals studied in *Ulva* decrease in the following order: Zn > Cu > Pb > Cd.

The concentration of cadmium (Cd) in *Ulva* was found between 0.24 and 0.66 mg/kg, with a mean concentration of 0.39 ± 0.18 mg/kg dry weight. The average concentration was high in station S2 compared to stations S1 and S3. The average cadmium content bioaccumulated by sea lettuce exceeds the standards of the Mediterranean coastal areas (0.2 mg/kg dry weight), as determined by the F.A.O (1994). These figures also indicate that the cadmium levels exceed the official standards of the European Communities (N.O.C.E), which sets a threshold of 0.05 mg/kg dry weight in algae, edible herbs. Previous works on this species report the same conclusion on the Moroccan coast (Kaimoussi et al., 2004, 2005). The concentrations accumulated in *Ulva* range from about 0.35 to 1.4 mg/kg dry weight, with an average of 0.92 mg /kg dry weight. In *Fucus spiralis*, the concentration varies from 0.84 to 5.20 mg/kg dry weight, with an average of 2.41 mg/kg dry weight. According to the previous works of Stenner and Nikless (1975), it was found that green algae, such as the *Fucus* sp. can accumulate cadmium with values from 0.8 to 7.4 mg/kg dry weight; it is 0.8–7.4 mg/kg dry weight for *Enteromorpha* sp. and 0.5–4.1 mg/kg dry weight for *Ulva lactuca*. The same bioaccumulation effect was noted in some other works about the Italian coast. Indeed, an average cadmium concentration of 0.29 mg/kg dry weight was reported in the works of Campanella et al. (2001). According to Storelli et al., 2001, this concentration is 0.20 mg/kg dry weight in *U. lactuca*; it varies between 0.14 and 0.60 mg/kg. Some recent works by Conti and Finoia (2010) related to *Posidonia pavonica* indicated that a normal cadmium bioaccumulation between 0.24 and 1.66 mg/kg dry weight was found on the Italian coastline. Therefore, it is in this reality that sea lettuce can be classified as a bioaccumulator of trace metals; it is the most sensitive species to metal pollution. Sea lettuce is obviously a bioindicator of pollution, especially in the case of cadmium on most Mediterranean coasts (Kaimoussi et al., 2004). Indeed, the studied *Ulva* sp. shows a cadmium contamination in station S2 in the area of Honaine; this is below the threshold limit requested by the FAO standards and classification (NOC. The bioaccumulated cadmium content may be attributed to the receiving environment.

Lead concentration in *Ulva* was found between 0.62 and 0.91 mg/kg, with a mean value of 0.62 ± 0.26 mg/kg dry weight. The average concentration was found to be high in station S1 as compared to stations S2 and S3. The average content of lead bioaccumulated by our species does not exceed the standards in the Mediterranean coastal areas, as prescribed by FAO which requires a limit of 8.3 mg/kg dry weight (F.A.O, 1994) The annual average lead content is 0.62 mg/kg dry weight; it still remains within the standards. Nevertheless, these lead levels are higher than the official European standards, which set a threshold limit of 0.1 mg/kg dry weight for edible plants**.**

Stenner and Nickless (1975*)* conducted a study on the Moroccan, Spanish and Portuguese coasts and found that green algae, such as *Fucus* sp., can accumulate lead between 5 and 13 mg/kg dry weight. It can be between 4 and 22 mg/kg dry weight in *Enteromorpha* sp.

and can go up to 10 mg/kg dry weight in *Ulva lactuca*. More recently, Storelli et al. (2001) have led some works about the Italian coasts; they indicated that the average concentrations are much lower than 0.84 mg/kg dry weight in *Ulva*. According to Conti and Finoia (2010), lead concentrations are set between 1.43 and 7.44 mg/kg dry weight in algae *Posidonia pavonica*. However, according to Campanella et al. (2001), the average lead concentration is equal to 14.7 mg/kg dry weight in sea lettuce. From these results, this species *Ulva lactuca* can be considered as a pollution bioindicator on the Mediterranean coast (Brown et al., 1999) The studied species shows lead contamination in station S1 in the region of Beni Saf, according to standards (NOCE).

The concentration of copper (Cu) in *Ulva* was found between 4.35 and 5.86 mg/kg, with an average concentration of 4.85 ± 0.98 mg/kg dry weight. The average concentration was higher in station S2 compared to stations S1 and S3. The average bioaccumulated copper content in this actual species did not exceed the standards on the Mediterranean coastal areas, as required by the FAO, with a level of 6.9 mg/kg dry weight. Previous works on this same species reported the same observation on the Moroccan coast. According to Kaimoussi et al. (2004, 2005), the concentrations accumulated in *Ulva* vary from 5.5 to 21.5 mg/kg dry weight, with an average concentration of 14.5 mg/kg dry weight. In *Fucus spiralis*, concentrations between 4.1 and 11.5 mg/kg dry weight, with an average concentration of 6.1 mg/kg dry weight, have been reported. In a study on the Spanish coast, Stenner and Nikless (1975) found that green algae, such as *Ulva lactuca*, can accumulate copper with concentrations ranging from 5.5 to 31 mg/kg dry weight. It is worth mentioning that the species under study was not found to be contaminated by copper in the stations; they were not affected by this metal throughout the seasons.

However, the receiving environment was contaminated with copper, but this has clearly not affected the species studied (Shiber, Washburn, 1978). Seasonal fluctuations of metal concentrations in algae were often observed (Pohl et al., 1993). However, the growth activities alone are not responsible for the difference in the seasonal variations between metals. These variations could also result from the temporal changes of metal contents in the surrounding seawater (Phillips, 1994). Metal content in marine macro-algae is generally low during the warm months, because of the high growth rates, which 'dilute' the accumulated metals (Pohl et al.,1993). However, Hägerhäll (1973) announced that copper and zinc contents in *Ascophyllum nodosum* in Öresund (Sweden) were at their maximum in mid-July. Drude De Lacerda and Teixeira (1985) found that concentrations of Cd, Cu and Pb (amongst other metals) in five marine algae (sampling site in southern Brazil) were generally at their highest in January (summer) and at their minimum in August (winter). Similarly, Fernanda Leal et al. (1997) found that the levels of Cd, and Pb in both *Enteromorpha* sp. and *Porphyra* sp. were higher in the spring season (June–April) and winter (March–November). Some authors (Conti, Finoia, 2010) studied the seasonal variation of bioaccumulation of copper; they recorded almost identical models, with minimums in winter, probably because they have similar seasonal demand in metal enzymes containing copper (Sawidis, Voulgaropoulos, 1986). For other authors, the content of heavy metals in algae depends on the age of these same algae. Indeed, Forsberg et al. (1988) noted that the concentration of metals (Al, Co, Fe, Mn, Ni and Zn) in older thalli, which exceeded that in the growing ones, such as *Fucus* *vesiculosus*. In the case of sea lettuce, copper demand is much higher in the warm periods. This is well noted in station S2 in the area of Honaine.

The concentration of zinc (Zn) in *Ulva* is between 35.12 and 104 mg/kg, with an average concentration of 29.52 ± 30 mg/kg dry weight. The average concentration is higher in station S1 compared to stations S2 and S3. The average zinc content bioaccumulated by our species is slightly higher than the standards of the Mediterranean coastal areas, as required by FAO, for which the limit is set to 24.8 mg/kg dry weight (FAO, 1994). Stenner and Nickless (1975) led some works on the Moroccan, Spanish and Portuguese coasts and found out that green algae can accumulate zinc from 75 to 130 mg/kg dry weight in *Enteromorpha* sp. and from 37.2 to 116.5 mg/kg dry weight in algae. According to Fuge and James (1974), *Fucus vesiculosus* can, however, accumulate between 72.1 and 330.5 mg/kg dry weight . More recently, Storelli et al. (2010) have carried out investigations on Italian coasts and reported some average concentrations that exceed 127.27 mg/kg dry weight in *Ulva*. This concentration was found to vary between 34.39 and 192.17 mg/kg dry weight. On the other hand, according to Conti and Finoia (2010), zinc concentrations range from 29.1 to 67.7 mg/kg dry weight in algae *Posidonia pavonica*. According to the work of Campanella et al. (2001), the average zinc concentrations are set to 50 mg/kg dry weight in sea lettuce. Kaimoussi et al. (2004) conducted studies on the Moroccan coasts and noted much higher concentrations in *Ulva lactuca*, which can accumulate between 96 and 306 mg/kg dry weight, with an average concentration of 163 mg/kg dry weight.

According to some studies carried on the Mediterranean coast, the species *U. lactuca* can be classified as a bioindicator for zinc pollution (Brown et al., 1999). The species studied showed zinc contamination in station S2 in the area of Honaine; station S1 in the region of Beni Saf, and a slight contamination in station S3 in the port area of Honaine (FAO, 1994).

- The metal concentrations observed in sea lettuce *U. lactuca* in both coastal areas of Beni Saf and Honaine did not show excessively high levels to present a risk of contamination. Nevertheless, cadmium and lead, which are considered as toxic metals and belong to the class of toxic metals, could be detected because they were found at levels higher than those required by FAO standards (1994) and by the European Communities NOCE (2001). Therefore, *U. lactuca* was effectively contaminated with lead in the port of Beni Saf (S1) and slightly contaminated in the port of Honaine (S3); it also contained some cadmium in the coastal region of Honaine (S2). Amongst the metals that are essential to the formation of coastal algae, zinc seems to be more abundant than copper. Comparing our data with those from the literature, for the same species collected in polluted or unpolluted areas, shows that the concentrations of Cd and Cu are intermediate between the limits given in the literature, although, in many cases, these levels show lower values than those found in other geographic areas (Munda, Hudnik, 1991; Seeliger, Edwards, 1987; Stenner, Nickless, 1975; Dumon et al., 1994; Güven et al., 1993). Thus, the studied species was slightly contaminated with zinc in most of the three stations, S1, S2 and S3, particularly in the port of Beni Saf. Obviously, this is probably due at first to the species' needs to bioaccumulate zinc, which is 10–100 mg/kg dry weight of the species' needs to produce its chlorophyll and to grow. In other studies, Rodica et al. (2006) revealed average concentrations of zinc (32.8 mg/kg dry weight), copper (9.4 mg/g dry matter of copper) and lead (4 mg/g dry weight) in *U. rigida* in Romania. The value found

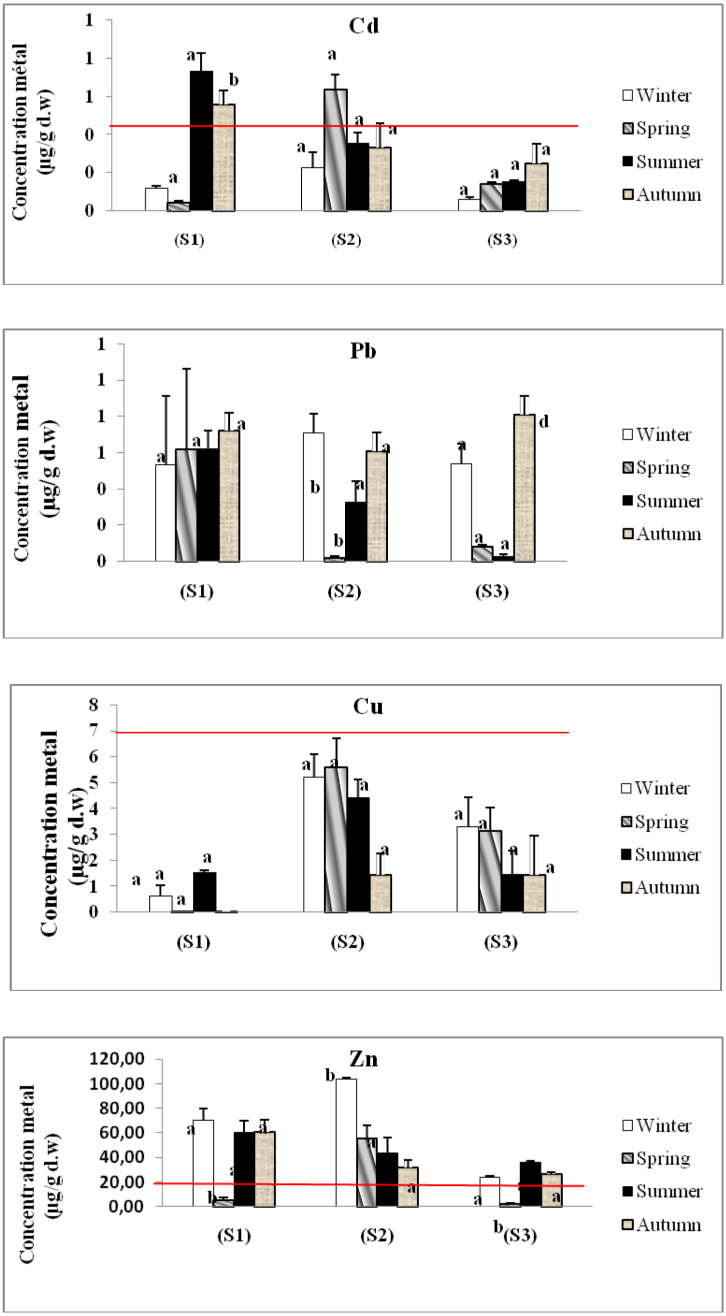

Fig. 3. Seasonal variations in the metal concentrations (Cd, Pb, Cu and Zn) in mg/kg (dry weight) in sea lettuce *Ulva lactuca* levied at the two coastal areas of Beni Saf and Honaine in (western Algerian coast).

for zinc was 2–16 mg/kg dry weight in 100 g dry weight in *Ulva* in Morocco (F.E.N.I.P, 2015). In addition, considering the French Standards, food marine plants require less than 5 mg/kg of lead and less than 0.5 mg/kg of cadmium (Perez, 1997).

Conclusion

The study of the four heavy metals (Cd, Pb, Cu and Zn) in sea lettuce *Ulva lactuca* on the western coastlines of Beni Saf and Honaine showed that their concentrations vary with the sampling site and the season (Fig. 3). The heavy metal levels generally increase from winter to summer. Except for cadmium, the highest heavy metal concentrations were detected in station S2, which receives the discharges of urban waste water from the town of Ouled Youcef (collector C2). However, it was noted that the species under study in the coast areas of Beni Saf and Honaine was very slightly contaminated by Copper (Cu). The concentrations of Zn in the same species were found to be significant. The accumulation of heavy metals generally follows this order: Zn > Cu > Pb > Cd (Nouri, Haddioui, 2016).

The presence of heavy metals in algae on the coasts of Beni Saf and Honaine is lower than that recorded in other parts of the world. With the urban intensification and port activities, the heavy metal levels will continue to increase, and, consequently, the purification of waste waters by a suitable treatment plant system becomes necessary if one wants to preserve the aquatic ecosystem balance in these regions, which may be in danger in the coming years. It is recognised that marine algae have therapeutic properties and can provide nutritional virtues to humans.

Algae can provide a balanced diet, proper prevention of lifestyle-related diseases and better health conditions in many areas. Thanks to the modern techniques of preparation, preservation and packaging, algae are now within the reach of all. It is necessary to develop and take advantage of these potential concentrates for our health and beauty. Therefore, algae, in general, and particularly those belonging to the algal Class of Chlorophyceae, which contains *Ulva*, have a huge medical, pharmaceutical and cosmetic potential; they have a significant impact on the economy, food industry and so on.

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BIRD COMMUNITIES AND VEGETATION COMPOSITION IN NATURAL AND SEMI-NATURAL FORESTS OF MEGALOPOLIS: CORRELATIONS AND COMPARISONS OF DIVERSITY INDICES (KYIV CITY, UKRAINE)

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Abstract

Blinkova O., Shupova T.: Bird communities and vegetation composition in natural and semi-natural forests of megalopolis: correlations and comparisons of diversity indices (Kyiv city, Ukraine). Ekológia (Bratislava), Vol. 37, No. 3, p. 259–288, 2018.

Assessment of correlations and comparisons of diversity indices between birds communities and vegetation composition of the forest ecosystem is an important subject of synecological research to identify the intensity of human impact on the flora and fauna in megalopolis. Urban recreation is one of the major causes of violation of the structural and functional integrity of the forest ecosystem. Studies on avian complex and phytocoenosis have focused on the impact of urban recreation on the soil surface, compositions of trees, shrub and herbaceous layers and species, trophic and ecological compositions of nesting-birds and feeding-birds communities. This article compares the measurement of the diversity of bird communities and forestry vegetation (diversity indices, dominance indices, evenness indices) in the natural and semi-natural forests of the Kyiv city on a gradient of recreational transformation. The stands formed consist of *Quercus robur* L., *Carpinus betulus* L., *Acer platanoides* L., *Tilia cordata* L., *Ulmus glabra* Huds., *Fraxinus excelsior* L. and *Prunus avium* L. The floristic list comprised 65 grass species. A total of 49 species of avifauna were found, including 44 species that were protected by the Bern, Bonn and Washington Conventions. There were significant correlations between vertical and horizontal heterogeneities of tree distribution and abundance, species richness and nesting density of birds. The interrelationship between species diversity of birds and floristic richness was also confirmed.

Key words: plant vegetation; avifauna; indices of diversity, dominance, and evenness; recreational transformation.

Introduction

Forests play a core role in biosphere stability because of the significant area, capacity, duration of development, forest productivity and complexity of structural and functional organisation (Migunova, 1993; Mirkin et al., 2002). The response of a forest ecosystem to changing environmental conditions is determined by its biological resources (Ramenskii, 1971; Rabotnov, 1992; Mirkin et al., 2002; Blinkova, 2014; Blinkova, Shupova, 2017; Blinkova, Ivanenko, 2018). Natural and semi-natural forests play an important role of buffer elements in the composition of urbanised landscapes regarding the spread and reduction of the negative impact of anthropogenic factors. Forest ecosystems of megalopolis have a significant anthropogenic transformation.

Urban recreation is one of the main anthropogenic factors that lead to a significant transformation of integrity of natural and semi-natural forests of megalopolis in Ukraine. An assessment of the consequences of the recreational impact on forest ecosystems should be carried with synecological analysis of a relationship between the phyto- and zoo-components. Furthermore, numerous studies in forested areas have emphasised the importance of urbanisation gradient to examine the response of the biotic community. It is well known that mechanical human impact on forest is manifested in trampling of leaf litter, surface soil compaction and mechanical damage to trees and herbaceous cover (Rusin, 2003; Blinkova, 2014; Lavrov et al., 2016, a,b). These violations lead to changes in ecological regimes in the forest ecosystem. This causes structural and functional changes in the fauna, in particular in the species, taxonomic, trophic and ecological composition of the birds' ecological groups (guilds) (Blinkova, Shupova, 2017).

Birds are a particularly advantageous taxonomic group that is visually and acoustically conspicuous and can thus provide an efficient means of evaluating habitat change in forest ecosystems (Sekercioğlu, 2006; Etterson et al., 2007; Fischer et al., 2007; Gardner et al., 2008; Whelan et al., 2008). Increasing urbanisation often results in simplified habitats, a community of birds with fewer species dominated by abundant non-native species and changes in guilds of birds (Marzluff et al., 1998). Variations of characteristics of the forest ecosystem, formed under the influence of urban recreation, have shown the relationships between phytocoenotic parameters and species diversity and density of nesting birds (Conner, Dickson, 1997; Chaplygina et al., 2016; Blinkova, Shupova, 2017). The approaches to relationships between birds communities and forest compositions based on the measurement of phytocoenotic parameters, indices of vertical and horizontal heterogeneities, species diversity and density of breeding birds (MacArthur R., MacArthur J., 1961; Wilson, 1974; O'Connor, 1981; Kurlavichus, 1986; Fuller, Moreton, 1987; Wilson et al., 1994; Catsadorakis, 1997; Walther, 2002). Availability of data about the transformation of the evolutionally formed consortium relation between forest vegetation and birds composition will deepen the knowledge about anthropogenic changes in the state, productivity and development of forest ecosystems (Chaplygina, 2015; Blinkova, Shupova, 2017; Blinkova, Ivanenko, 2018).

The aim of the study was to evaluate correlations and indices of diversity between bird communities and vegetation composition in natural and semi-natural forests in urban conditions depending on the degree of recreational transformation of the environment.

Material and methods

Study site

Study sites were all located within the Kyiv city. The natural and semi-natural forests are located inside the city. Kyiv is located on the right and left banks of the Dnipro River at the border between the Forest-Steppe zone and the

Polissya of Ukraine following the geo-botanical division of Ukraine (Biluk, 1977). The area of the city is 835.6 km², of which 31,300 ha are natural and semi-natural forests. The average annual temperature for the period 2016–2017 was 8.8 °C. The climate is a semi-continental type for the Forest-Steppe zone. The geomorphological structure of Kyiv belongs to 3 geomorphological zones: South Polissya, Dnipro, Azov-Dnipro Soddy-podzolic soils, gray forest soils and sod meadow soils are the main soil types in Kyiv (Gavriluk, 1956). In the survey conducted between 12 and 25 June 2016, we distinguished 4 localities of forests in Kyiv city. All localities were belonged to the nature reserve fund of Ukraine (Table 1).

T a b l e 1. General characteristics of studied forests.

EP No.*	Name of tract	GPS coordinates	Year established	Affiliation to the nature reserve fund	Area (ha)	Phytogenesis
1	Teremky	50°21 ′40″N, 30°27 ′15″E	2007	National Natural Park “Holosiivskyi”	93.8	Natural vegetation
2	Holosiivskyi lis	50°22 ′01″N, 30°30 ′30″E	2007	National Natural Park “Holosiivskyi”	1879.43	Natural vegetation
3	Lysa Hora	50°23 ′42″N, 30°32 ′53″E	1994	Historical and cultural monument-museum “Kyivska fortetsia”	137.1	Semi-natural vegetation
4	Nivki	50°27′40″N, 30°25′13″E	1972	Monument of landscape art of national importance	44.94	Semi-natural vegetation

Note: *The location of experimental plots.

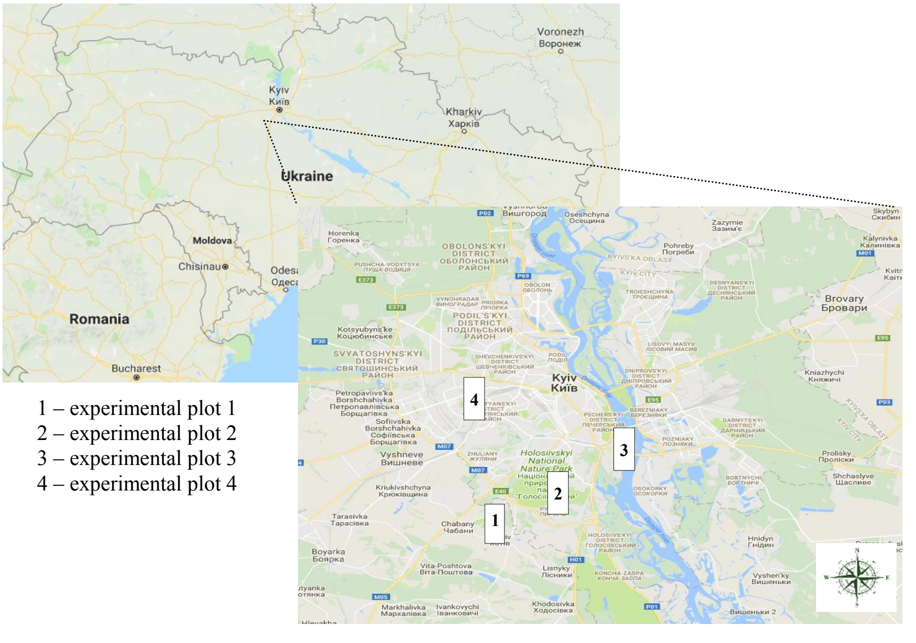


Fig. 1. Geographical distribution of the studied area. The symbols indicate the location and the number of experimental plots.

Data collection and processing

The urban forests were selected for the analyses because recreational impact is maximised in these objects. Walking tracks and children's sports grounds are available in all model forests. Each experimental plot was established according to the detailed route-method of study (Dilis, 1974; Vasilevich, 1992; Mirkin et al., 2002). The experimental plots (EPs) that are representative of the forests were chosen by reconnaissance method of study. According to reconnaissance observations of recreational data, the EPs were divided into 4 types, designated as intensive (EP4; 0.75 ha), medium (EP3; 0.74 ha), moderate (EP2; 0.76 ha) and weak (EP1; 0.70 ha) stages of recreational transformation of biotope (Fig. 1).

Birds were nesting during this period. Passeriformes were actively singing or feeding chicks. At the same time, they were clearly visible. Observations of the birds were carried out during morning (7.00–11.00) or evening (18.00–19.30). The weather conditions were favourable for bird surveys. The wind was absent. The air temperature was 25–28 °C. The song activity of Passeriformes was high.

The state of the soil surface layer was determined according to Polyakov and Plugatar (2009). The state of soil surface layer was classified into the following categories: 1, undisturbed soil; 2, weakened mulch (single passes); 3, footpath in mulch; 4, footpath or road without mulch; 5, footpath or road with washaways; 6, deposition and washaways made by recreants descending on steep slopes. The stages of digression of soil surface layer were the following: stage I, under which the 3rd, 4th, 5th and 6th categories of disturbance cover up to 2% of the area of experimental plot; stage II, from 2% to 10% of area; stage III, 10–25% of area; stage IV, 26–40% of area; stage V, more than 40% of the site area. The stages of the recreational transformation were assessed according to Rusin (2003) (Table 2).

T a b l e 2. Recreational transformation of urban forest ecosystem is shown via basic characteristics of the change in state of herbaceous cover, leaf-litter, tree stratum, undergrowth and soil surface. Degradation stages of transformation are shown.

Digression stage	Herbaceous cover and leaf-litter	Tree stratum and undergrowth	Soil surface
1	Full species composition of herbaceous plant, projective cover is 90–100%, leaf-litter is not broken	Trees are healthy, undergrowth is numerous and different ages	Stage I of digression
2	Appearance of ruderal, pratal herbaceous species, projective cover is 80–90%, leaf-litter begins to trample down	Trees are weakened, undergrowth is numerous but not different ages	Stage II of digression
3	Share of ruderal, pratal herbaceous species is 5–10%, projective cover is 70–80%, leaf-litter is trample down	Trees are weakened or heavily weakened, undergrowth is limited	Stage III of digression
4	Share of ruderal or pratal herbaceous species is 10–20%, projective cover is 50–70%, leaf-litter begins to deteriorate	Trees are heavily weakened, low viability of undergrowth is located clumps	Stage IV of digression
5	Share of ruderal or pratal herbaceous species are dominating species, projective cover is 0–50%, leaf-litter is completely absent	Trees are heavily weakened or wilting with significant mechanical damage, undergrowth is absent	Stage V of digression

Herbaceous layer assessment

Plant composition of all EPs was established according to the botanical detailed route method (Neshataev, 1987; Didukh, 1994; Mirkin et al., 2002). Taxa nomenclature was adopted from Mosyakin and Fedoronchuk (1999), taking into account the existing 'International Code of Nomenclature for algae, fungi, and plants' (Mcneill, 2011). To appraise the diversity of species, the Braun-Blanquet scale (Braun-Blanquet, 1964) was used. The adventive index was calculated as a percentage of the adventitious species encountered at EP (Burda, 2006).

The health condition of trees (category of state trees) was appraised in accordance with the Sanitary Forest Regulation in Ukraine (2016). The stand state index was calculated as a sum of the values of the tree state index of trees in a certain category divided by the total number of examined trees:

$$I_C = \frac{\sum k_i \cdot n_i}{N},$$

where k_i is the category of tree state (I–VI), n_i is the number of trees in a certain category of tree state and N is the total number of trees.

The stands with index values ranging from 1 to 1.5 are considered as healthy (I), 1.51–2.50 as weaker ones (II), 2.51–3.50 as heavily weakened ones (III), 3.51–4.50 as wilting ones (IV), 4.51–5.50 as recently dead (V) and 5.51–6.50 as old dead stands (VI).

In order to avoid the influence of the irregular intensity of silvicultural practice on the index of stand state, for each category of states, the weighted average Kraft classes (WAKC; vitality composition of tree vegetation) were calculated as the sum of the number of trees of each Kraft class multiplied by stand state index (I–V), which was divided by the total number trees in a certain category of state (Eytungen, 1949).

$$WAKC = \frac{\sum k_{kc} \times I_C}{n_i},$$

where k_{kc} is the number of trees in each Kraft class, I_c is the index of the stand state and n_i is the number of trees in a certain state category.

For each stand, forest mensuration parameters were estimated: age (A), average weighted diameter (D_{ave}), average weighted height (H_{ave}), fluctuations range (D_{min}–D_{max}; H_{min}–H_{max}), standard deviation (SD), stand density (N) and stand basal area as a sum of tree areas (G_n). Morphometric parameters were calculated by an optical altimeter (Suunto PM-5) and callipers (Waldmeister100 alu). Mechanically damaged woody plants were the trees and bushes that have cut or sawn live branch, injury on the stem reaching cambium or prominent features of such damage independent of time such were inflicted.

Birds surveys

Bird communities of all EPs was researched according to the transect method (Novikov, 1953; Järvinen, Väisänen, 1975; Bibby et al., 2000). Transect surveys were used to compare the differences in birds between EPs. The length of transect was 0.800–1.000 m. The width on both sides of the direction of movement was 50 m. Nine transects were established on all EPs. Taxa nomenclature of birds was adopted by International Code of the Zoological Nomenclature (1999). The species of birds and the search for their nests in tree canopies visually were determined using binoculars (Barska X-Trail 10x50 Reverse Porro). The audio definition of birds' voices (mp3) was used for the acoustic identification of species.

The density of bird-feeding stations was determined by the number of individuals of each species per 1 km transect. The SD was calculated for the average density of nesting birds by the number of pair per 1 km transect. Singing male was counted as a nesting pair for passerine species (Novikov, 1953). The status of the species (breeding, feeding and migration) was determined by the behaviour or presence of a nest for non-Passeriformes species. Community of breeding birds and community of feeding birds were analysed separately.

We also classified bird species into different categories (ecological groups) according to the patterns of microhabitat choice (Muntaner et al., 1983; Snow, Perrins, 1998; Martin, Eadie, 1999**;** Shirihia et al., 2001; Zavjalov et al., 2005; Camprodon, Brotons, 2006; Bragin E., Bragina T., 2014; Atemasova, 2015). Woody nesters are species of the shrub layer of the undergrowth or tree layer. The individuals of this category are divided into 2 groups: tree canopies nesters and tree hollow nesters. The tree hollow nesters are divided into primary, birds that make hollows (*Picidae*), and secondary ones, those that settle in ready-made hollows. The category of ground nesters includes birds associated with the forest open habitats. The category of cavity nesters includes birds associated with vertically dissected relief (cracks in rocks, trees, stumps). The category of building nesters includes birds associated with urban construction (in particular, secondary synanthroposized tree hollow nesters or cavity nesters).

We classified bird species into different categories according to the type of feeding: insectivorous birds (these birds feed insects and other invertebrates, *Scolopacidae, Motacillidae, Sylviidae, Muscicapidae*), granivorous birds (these birds feed grain of plants, *Columbidae*), birds with mixed type of feeding (e.g. *Picidae, Paridae, Fringillidae*), predatory birds (these birds hunt and feed on rodents and other small animals, *Falconiformes* and *Strigiformes*) and pantophagous birds (these birds feed all types of feeding, *Corvidae*) (Camprodon, Brotons 2006).

The sinantropisation index of nesting birds was determined according to the equation of Jedryczkowski (Klausnitzer, 1990)

$$W_s = \frac{L_s}{L_o} ,$$

where L_s is the number of synanthropic species and L_o is a total number of species.

Species of birds forming synanthropic and natural populations were isolated simultaneously into the group of hemysynanthropes (Klausnitzer, 1990). The birds protected by the 'International Conventions for the Protection of Birds' were listed.

Statistical analyses

For the assessment of plants and birds biodiversity, various methods and indices are available. In this study, the indices of diversity, dominance and equalisation were used for each EP (Magurran, 1998):

1. relative abundance of species or guild

$$P_i = \frac{N_i}{N},$$

2. the indices of dominance

$$d = \frac{Ni_{max}}{N} \quad \text{Berger–Parker}$$

$$\lambda = \sum_{i=1}^{S} \left[\frac{N_i}{N}\right]^2 \quad \text{Simpson}$$

$$U = \frac{(N-U)}{(N-\sqrt{N})}, \; U = \sqrt{\sum N_i^2} \quad \text{McIntosh}$$

3. the indices of diversity

$$H = -\sum p_i \log_2 \rho_i \quad \text{Shannon}$$

$$D_{Mn} = \frac{S}{\sqrt{N}} \quad \text{Menchinick}$$

$$D_{Mg} = \frac{(S-1)}{\ln N} \quad \text{Margalef}$$

$$Ds = \frac{1}{\lambda} \quad \text{Simpson}$$

4. the indices of evenness

$$E = \frac{H^i}{\ln S} \quad \text{Pielou}$$

$$Us = \sqrt{\sum N_i^2}, \; E = \frac{N-U}{N-\frac{N}{\sqrt{S}}} \quad \text{McIntosh}$$

where N_i is the density of the species in communities, N is the total number of individuals (for plants, the number of individuals per hectare; for birds, the number of individuals per kilometre), N_{max} is the maximum value of N_i, U is the McIntosh index of diversity, p_i is the ratio of each species, S is the total number of the species, λ is the Simpson index of dominance and H' is Shannon's index of diversity.

Indices of horizontal heterogeneity of vegetation (IHH) and vertical heterogeneity of vegetation (IVH) were calculated in order to describe the vegetation composition in the urban forest ecosystems the feeding and breeding stations of birds (Blondel, Curvillier, 1977; Erdelen, 1984). IVH is Shannon's index for vertical vegetation distributions, taking the number of vegetation that touches at each height as individuals in that class. IHH is the coefficient of variation of point-centred quarter distance between the trees (AD).

$$IHH = \frac{S.D.\ AD}{AD_{ave}}$$

As higher habitat structural heterogeneity often increases, bird species richness because of the presence of more diverse nesting and foraging resources (MacArthur R., MacArthur J., 1961). IHH is the lowest if trees are distributed uniformly but is higher for a random distribution (Sekercioğlu, 2002).

Results

Assessment of stands morphometric parameters

The stands at all EP were 2 storeyed. The age composition of stands consisted mainly of trees of the same age (60–80 years). The first storey composed of *Quercus robur* L. and *Carpinus betulus* L. The second storey composed of *Tilia cordata* Mill., *Acer platanoides* L., *Fraxinus ex-*

T a b l e 3. Characteristic of dominant woody vegetation. Variation of forest mensuration parameters for *Quercus robur*, *Acer platanoides*, *Carpinus betulus*, *Tilia cordata*, *Fraxinus excelsior* and *Ulmus glabra* is presented.

EP No.	Species	Age (years)	N (pieces)	D_{ave} (cm)	D_{min}-D_{max}; SD	H_{ave} (m)	H_{min}-H_{max};SD	P	G_n ($m^2\ ha^{-1}$)
1	*Q. robur*	60–80	172	88.1	63.2–95.1; 8.38	19.0	16.1–24.2; 2.15	0.7–0.8	139.1
	A. platanoides	40–60	134	25.4	21.6–45.9; 8.99	15.4	13.8–18.2;2.01		81.2
	C. betulus	60–80	108	28.9	20.8–34.3; 5.18	16.8	14.2–18.0; 1.75		66.4
	P. avium	40–60	51	32.7	28.7–39.6; 4.67	14.8	12.6–18.3; 2.38		27.1
2	*Q. robur*	60–80	160	82.5	75.8–120.4; 9.21	17.7	14.9–19.3; 1.99	0.6–0.7	199.4
	C. betulus	60–80	201	29.8	23.5–40.5; 5.98	17.1	15.4–19.2; 2.14		99.3
	T. cordata	60–80	74	33.4	22.5–38.3; 8.01	15.7	13.0–16.9; 1.60		54.8
	A. platanoides	40–60	92	26.3	21.4–35.5; 4.86	13.8	12.7–15.4;1.65		63.1
3	*Q. robur*	60–80	122	86.1	77.1–118.5; 8.17	18.0	15.3–20.1; 1.96	0.6–0.7	125.7
	C. betulus	60–80	64	25.6	19.5–34.2; 5.12	17.3	14.3–18.1; 1.08		54.2
	A. platanoides	40–60	75	24.0	18.3–30.4; 6.79	14.3	11.7–17.0; 1.96		70.6
	T. cordata	60–80	73	28.5	24.1–36.7; 8.74	15.1	12.2–17.6; 1.99		63.5
	F. excelsior	40–60	18	20.7	16.1–26.4; 3.88	14.6	13.5–16.8; 1.78		19.1
4	*Q. robur*	60–80	98	78.5	68.4–101.0; 9.12	16.9	14.7–18.8; 1.61	0.5–0.6	98.6
	C. betulus	60–80	78	22.4	17.0–28.5; 6.01	16.1	13.7–18.2; 1.67		28.7
	U. glabra	60–80	79	22.3	18.8–29.7; 7.41	13.9	11.8–15.1; 1.06		34.8
	T. cordata	40–60	65	22.8	20.4–34.5; 9.58	14.0	11.5–16.6; 1.78		46.2
	A. platanoides	40–60	81	18.7	15.1–27.8; 8.54	13.7	11.0–17.5; 2.47		57.1

celsior L., *Ulmus glabra* Huds. and *Prunus avium* L. The understorey composed of biogroups of *Corylus avellana* L., *Euonymus europaeus* L., *Euonymus verrucosa* Scop., *Crataegus oxyacantha* L., *Frangula alnus* Mill., *Sorbus aucuparia* L., *Cerasus avium* L. and *Rubus fruticous* L.

The analysis of material along the gradient of recreational transformation showed that the highest forest stand parameters (diameter, height, total number of trees and others) were in EP1. The magnitude of stand density was reduced from 0.8 (EP1) to 0.5 (EP4) because of a decrease in the proportion of *Quercus robur* and *Carpinus betulus*. The stand basal area was also reduced with the intensification of recreational impact: 199.4–98.6 $m^2 ha^{-1}$ (*Quercus robur*), 81.2–57.1 $m^2 ha^{-1}$ (*Acer platanoides*), 99.3–28.7 $m^2 ha^{-1}$ (*Carpinus betulus*), 63.5–46.2 $m^2 ha^{-1}$ (*Tilia cordata*) (Table 3). The number of trees at EPs significantly decreased along the gradient of recreational transformation.

The maximum values of this parameter for *Quercus robur*, *Carpinus betulus*, *Acer platanoides* and *Tilia cordata* were detected in EP1 that were 5.2–11.0% higher than others EPs. The weighted average of diameters of all species at the studied EPs was reduced too (10.9%, *Quercus robur*; 22.4%, *Carpinus betulus*; 26.3%, *Acer platanoides*; 26.7%, *Tilia cordata*). The growth reduction of trees was observed. The violation of growth in height and diameter of trees was caused by the high intensity of recreational activity. Correlation relationship between height and diameter in EP3 and EP4 was lower compared to EP2 and EP1 (R^2_{EP4} = 0.69; R^2_{EP3} = 0.77; R^2_{EP2} = 0.89; R^2_{EP1} = 0.88). The regrowth of forest-forming species was better developed at less-transformed EPs. The regrowth of *Quercus robur* at EP4 was absent. It was deficient at other EPs (N = 0.24–1.81 thousand pieces/ha). The regrowth of *Acer platanoides* was optimal for formed forest conditions (N = 1.40–4.17 thousand pieces per ha). The regrowth of *Carpinus betulus* was composed irregularly (N_{EP4} = 0.9 thousand pieces per ha; N_{EP3} = 1.3; N_{EP2} = 1.5; N_{EP1} = 1.2 thousand pieces per ha).

In general, the average number of regrowth of forest-forming species gradually decreased with an increasing stage of recreational digression (Table 4). The increasing of distance between the trees from 254.6 cm to 345.5 cm was recorded at EPs. The value of the index of IVH varied depending on the stage of transformation too. The value of IVH was the lowest (1.93) in EP4 and the highest (2.97) in EP1 (Table 4). The value of IHH was 0.66, 0.79, 0.80 and 0.78 in EP1–EP4, respectively.

Tree health and vitality composition

The analysis of health conditions revealed a weak-stage degree of recreational transformation of biotope in EP1 and an intensive high-stage degree of recreational transformation of biotope in EP4 (Fig. 2). The proportion of healthy trees was 15.1% at EP4. The proportion of weakened trees was 24.2%, heavily weakened 44.8% (twice as much) and wilting 0.5%. The

T a b l e 4. Additional parameters of forest vegetation in different experimental plots. Average distance between trees, average density undergrowth, index of horizontal heterogeneity of vegetation (IHH) and index of vertical heterogeneity of vegetation (IVH) are shown.

Parameters	**EP 1**	**EP 2**	**EP 3**	**EP 4**
Average distance between trees (AD) (cm)	254.0 ± 5.1	275.7 ± 13.8	306.0 ± 15.3	345.5 ± 17.2
Average density regrowth (thousand pieces/ha)	6.87 ± 0.34	5.45 ± 0.27	3.54 ± 0.17	2.30 ± 0.11
IHH	0.78	0.80	0.79	0.66
IVH	2.97	2.44	2.15	1.93

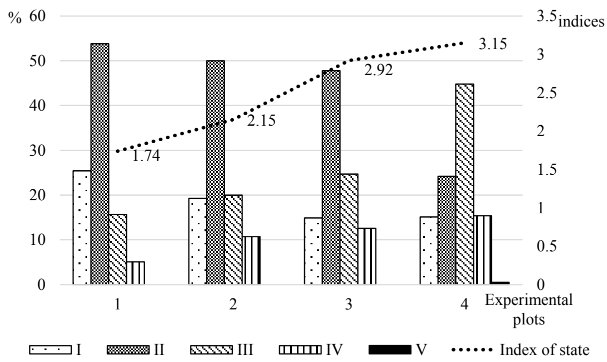


Fig. 2. Health conditions of forest stand in the experimental plots.

T a b l e 5. Vitality of tree composition in different experimental plots. The weighted average of Kraft class (WAKC) is shown.

EP No.	Categories of tree state				
	I	II	III	IV	V
	WAKC	WAKC	WAKC	WAKC	WAKC
1	1.8	2.1	4.0	4.2	-
2	1.9	2.2	3.8	4.0	-
3	1.5	2.4	2.6	3.1	-
4	2.1	2.1	2.0	3.6	4.8

proportion of healthy trees was increased from 14.9% (EP2) to 25.4% (EP1) with reduced impact on biotopes. The proportion of weakened trees was increased too (24.2–53.8%). Instead, the proportion of wilting trees gradually decreased from 44.8% to 15.7%. Recently dead stands were present only in EP4 (0.5%). The index of stand state was 1.74 (EP1), 2.15 (EP2), 2.92 (EP3) and 3.15 (EP4).

The analysis of the vitality of stands revealed a similar trend regarding the distribution of categories of tree state. The number of trees of the highest Kraft classes dominated at EP1 with a weak-stage degree of recreational transformation of biotope. WAKC of wilting (WAKC = 4.2) and heavily weakened (WAKC = 4.0) in EP1 differed from the data of other EPs (Table 5).

The value of WAKC revealed the absence of pathological processes in EP1. Drying of trees was natural process because of the biological characteristics of species in this EP. WAKC of weakened (WAKC = 2.2) and heavily weakened (WAKC = 3.8) were in EP2. WAKC of weakened (WAKC = 2.4) and heavily weakened (WAKC = 2.6) were in EP3. Trees of II and III classes Kraft began to wither in EP2. The trees of the lowest Kraft classes dominated at EP4 with an intensive-stage degree of recreational transformation of biotope. WAKC of healthy (WAKC=2.1), weakened (WAKC=2.1) and heavily weakened (WAKC=2.0) were in EP4.

The analysis of vitality composition as an integral index of the population state of *Quercus robur*, *Carpinus betulus*, *Acer. platanoides* and *Tilia cordata* indicated significant transformation of these species in intensive and medium recreational transformation EP4–EP3 compared with moderate and weak recreational transformation EP2–EP1.

Herbaceous and soil surface layers

The floristic list of the all EPs comprised 65 grass species belonging to 59 genera, 19 families. It included species of *Liliopsida* and *Magnoliopsida*. The prevailing families of herbal plants were *Asteraceae* (18 species, 27.5%) and *Poaceae* (10 species, 15.3%). Species of

Asteraceae and *Poaceae* dominated in the disturbed habitats. These were followed by *Lamiaceae* (5 species, 7.5%) and *Rosaceae* (4 species, 6.2%). *Fabaceae* and *Ranunculaceae* had the same distribution of species (3 species, 4.5%). *Brassicaceae*, *Polygonaceae* and *Scorphulariaceae* were represented by 2 species (3.0%). Sixteen families were represented by 1 species (1.5%).

The most florist saturation (49 species) was detected at the EP1. The projected cover was 83.5% and was dominated by *Asperula odorata* L., *Galium aparine* L., *Geranium sylvaticum* L., *Polygonatum odoratum* (Mill.) Druce and *Pulmonaria obscura* L. Ruderal and adventitious herbaceous species (*Chelidonium majus* L., *Malva sylvestris* L., *Plantago major* L., *Stenactis annua* L., *Urtica dioica* L.) were distributed sporadically. The total indicator of the state soil surface was stage II of digression. The total projected cover of herbaceous storey at the EP2 was 75.5% (33 species). A total of 9.0% species were ruderal or adventitious *(Dactylis glomerata, P. major, Senecio vulgaris* L.). Forest species were dominated (*Dryopteris filix-mas* L., *Carex sylvatica* L., *Geranium sanguineum* L., *Polygonatum multiflorum*). The soil surface was in stage III of degradation. The total projected cover of herbaceous storey at the EP3 was lower than that at the EP2 (65.5%; 29 species). The herbaceous storey was represented by ruderal and forest species (*Stellaria nemorum* L., *Asperula odorata* L., *Brachypodium sylvaticum* L., *Lamium galeobdolon* subsp., *Poa nemoralis* L., *P. odoratum* and *Stellaria holostea* L.). The soil surface was in stage III of degradation too. The herbaceous cover of EP4 is rather poor; the total projected cover was 55.5%. Altogether 21 species were found at EP4. Ruderal and pratal species were dominated at EP4. The indicator species composed of only biogroups of *Asarum europaeum* L. and *Galium aparine* (0.5%). The soil surface was in stage IV of degradation.

The *adventive index* was 45.5% (EP4), 29.5% (EP3), 18.1% (EP2) and 10.5% (EP1) at the ecoprofile. In accordance with the results, the stages of recreational transformation of EP were as follows: stage IV in EP4, stage III in EP3, stage II in EP2 and stage I in EP1.

Analysis of bird communities

Species composition of nesting birds

A total of 49 bird species belonging to 6 orders (*Falconiformes, Columbiformes, Cuculiformes, Caprimulgiformes, Piciformes* and *Passeriformes*) were observed during the study at the ecoprofile (Appendix 1). *Parus major, Fringilla coelebs* and *Turdus merula* dominated by their number in all communities of birds at EPs. These species are the most typical species in the forest biotopes of the region. This list was complemented by *Sitta europaea* (EP1), *Erithacus rubecula* (EP3), *Sturnus vulgaris* and *Turdus pilaris* (EP4). A total of 44 bird species (89.8%) were protected by the 'International Conventions for the Protection of Birds'. About 2 bird species (4.1%) were regionally rare species. Average density of nesting birds was 2.7 ± 0.60 pairs/km. The highest number of species was detected at the EP2 (36 species, average density – 2.6 ± 0.60 pairs/km). The number of nesting species was approximately the same in EP1 (36 species) and EP4 (33 species). The number of nesting species was the least in EP3 (28 species). The species from 4 orders were *nesting in EPs.*

Ecological and species compositions of nesting birds

In general, avifauna of all the EPs was distributed to the ecological groups: 38 species (76.6%) were woody nesters, 16 species (32.17%) were tree hollow nesters, 5 species (10.2%) were ground nesters and 4 species (8.2%) were building nesters. The relationship between birds communities at nesting stations and the digression stage of the forest ecosystem was absent in the medium (EP2) and moderate (EP3) stages of recreational transformation of biotope (Fig. 3).

The ratio of tree hollow nesters and tree canopies nesters were the same in all EPs. The ratio of ground nesters did not have a correlation relationship with the stage of recreational transformation but significantly reduced (to 9.1%) precisely in the most recreationally transformed EP4. In addition, 12.1% of birds was observed to use the territory of EP4 for nesting in buildings and structures. These species did not nest in EP4–EP3 with intensive and moderate levels of transformation biotope, although technical constructions were available. Only 1 species (*Passer montanus*) that used urban buildings and structures for nests was noted in EP4. It was a common species in the communities of birds. The average density of *P. montanus* was 3.6 ± 0.81 pairs/km. The birds that nest in urban buildings were present in EP1 and EP4 and absent in EP2 and EP3, because of the proximity of residential areas supplying migrants left without nesting stations (hollows) to the limit of their forest habitats. Sinantropisation of communities of nesting birds increased depending on the stage of recreational transformation of natural and semi-natural forests. The number of synanthropic species, their abundance in communities and the sinantropisation index of communities were gradually increased. On the contrary, the increase in appropriate data was significant in EP4 (Fig. 4).

The nesting obligatory synanthropes (*Columba livia* and *Phoenicurus ochruros*) were observed in the most transformed EP4. *P. ochruros* is an alien species of even land of Ukraine. The hemysynanthropic species, which have natural populations, were nested only in others EP. Share of species of birds those forming synanthropic populations was increased in the recreational transformation gradient in communities of feeding birds. The ratio of species increased by 1.5 times and was 45.7% (EP1), 50.0% (EP2), 50.0% (EP3) and 66.7% (EP4).

Woodpeckers are suppliers of breeding stacks to secondary tree hollow nesters, so it is necessary to consider their place in forest ecosystem. The species composition of the breeding woodpeckers decreased twice from the weak-transformed EP1 to the intensive-transformed EP4.

The abundance of nesting species of woodpeckers was minimal in EP2 and EP3. The density of woodpeckers increased in EP4, because *Dendrocopos major* nested in this EP with a density of 5.0 par km. This species is actively sinantrophised species and inhabited even small parks of urban residential areas. Most of the species of secondary tree hollow nesters was recorded in the EPs with high density of woodpeckers. The density of secondary tree hollow nesters was fluctuated in the EPs (Fig. 5).

The presence of artificial nests of birds and vents of anthropogenic origin in the fences were influenced by the quantitative indices of secondary hollow-nesting birds. In particular, the mass nesting of *Ficedula albicollis* in artificial nests of birds was recorded in EP2. Nesting of *Parus major* in vents of anthropogenic origin is a standard type of nesting. *Ficedula*

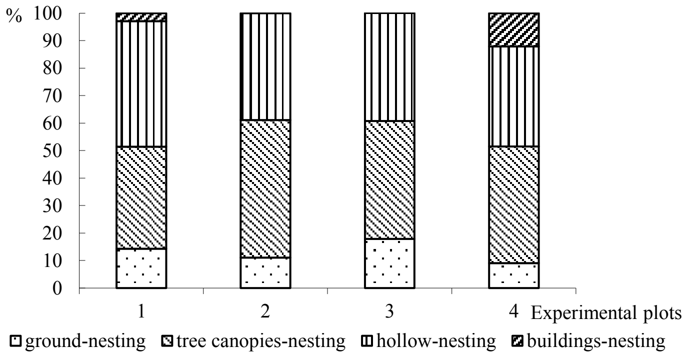


Fig. 3. Distribution of birds in communities by nesting stations.

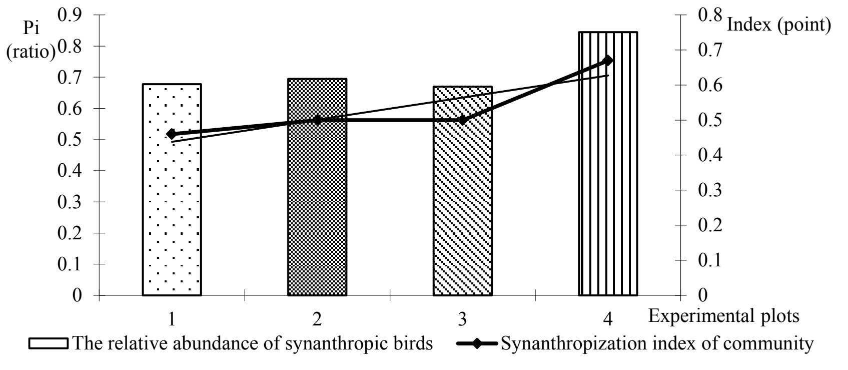


Fig. 4. Sinantropisation of communities of nesting birds.

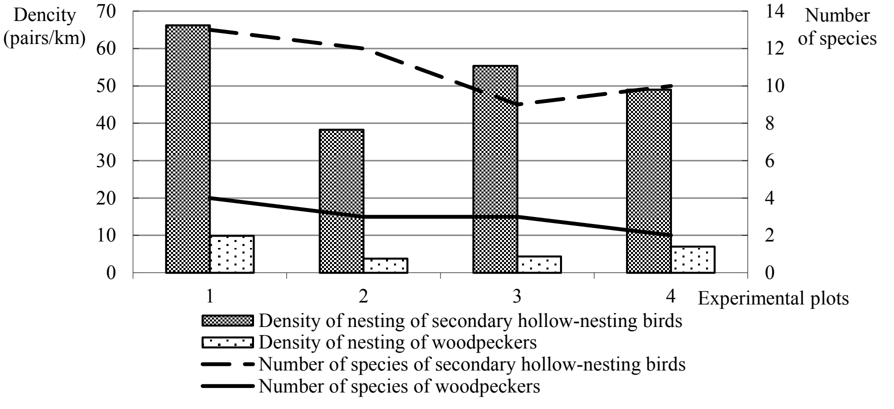


Fig. 5. The ratio of woodpeckers and secondary hollow-nesting birds in birds communities.

parva and *Parus palustris* are demanding species, which nest only in a slightly transformed EP (Appendix 1).

Trophic composition

Nesting birds of natural and semi-natural forests of Kiev were divided into 7 types of feeding (Fig. 6). The birds with mixed type of feeding (24 species, 47.1%) were dominated at the ecoprofile. About 18 species (31.4%) were birds that feed on invertebrates on the surface of ground. The predatory birds in the EPs were represented only by 1 species – the kestrel (*Falco tinnunculus*). Two species were insectivorous birds that catch insects in air: nightjar

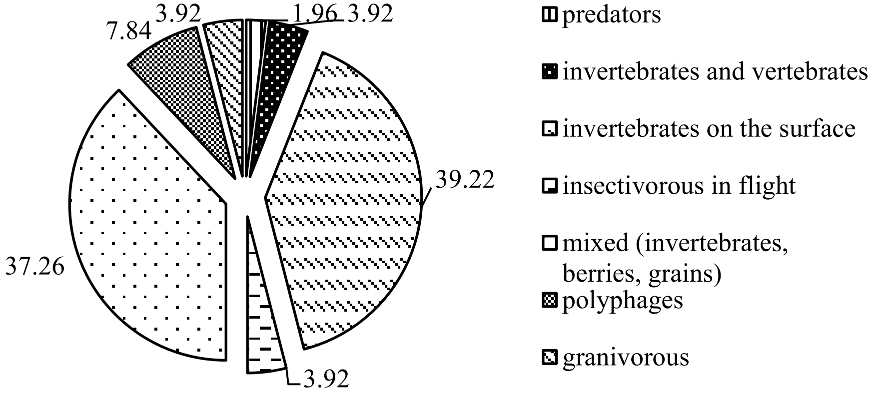


Fig. 6. The generalised distribution of avifauna of forest ecosystems of Kiev by types of feeding (in %).

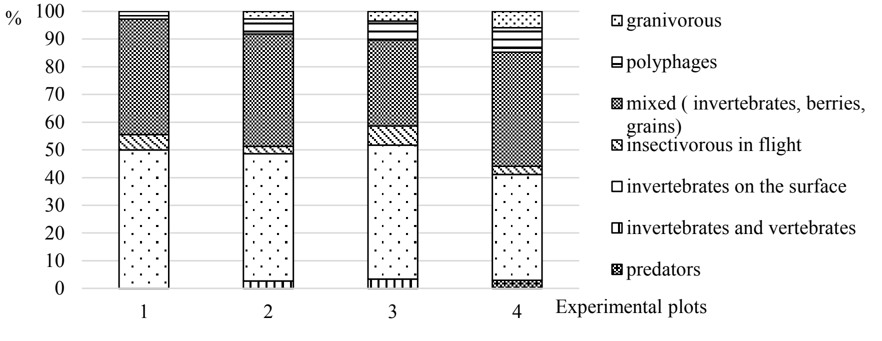


Fig. 7. Distribution of avifauna by types of feeding in experimental plots.

(*Caprimulgus europaeus*) and swift (*Apus apus*). *Caprimulgus europaeus* nested in EP1 and EP3. *Apus apus* did not nest in EP1 and EP3 but arrived from neighbouring residential areas only for feeding. Two granivorous species, woodpigeon (*Columba palumbus*) and rock dove (*C. livia*), were founded at ecoprofile. The trophic group of birds that feed on invertebrates and vertebrates (*Lanius*) were also represented by two species: *Lanius collurio* and *L. minor*. Polyphages were noted in small numbers: jay (*Garrulus glandarius*), magpie (*Pica pica*), hooded crow (*Corvus cornix*) and raven (*C. corax*).

The increase in the proportion of granivorous birds and birds with mixed type of feeding, including polyphages, was observed by the gradient of recreational transformation of the forest ecosystem (Fig. 7). Fluctuations in the ratio of other groups have not shown the tendency of dependence. The presence of predatory birds in the intensive-transformed EP4 was due to the fact that *Falco tinnunculus* is synanthropic species.

Assessment of plants and birds biodiversity

The assessment of plants and birds biodiversity indicated qualitatively anthropogenic changes in ecological conditions in urban natural and semi-natural forests. The violation of the species composition, density and species richness of communities of plants and birds were observed in EP2 and EP3 compared to the data from EP1 and EP4 (Figs. 8, 9). Indices of birds communities of EP2 differed significantly from the general trend at the ecoprofile. The most species richness and the number of nesting species with the lowest general and average breeding density were noted in EP2. Appropriate indices of plant communities were changed slowly, without sharp fluctuations. The highest average density of plant communities was recorded in the intensive recreational transformed EP4.

Diversity indices

The indices of diversity of phytocoenoses have shown anthropogenic changes in the ecological conditions of the forest ecosystem of Kyiv. The highest values of Shannon, Menchinick and Margalef indices were in EP1 (Fig. 10). The computed Shannon, Menchinick and Margalef indices for EP2 and EP3 were almost the same. The lowest values of these indices were in EP4, where adventitious and ruderal species had the highest share of phytocoenoses, stage IV of recreational transformation of biotope. Ecological conditions of EP4 were favourable only for dominate adventitious and ruderal species. Other species were in a depressed state. It should be noted that the synchronisation of the indices was violated precisely in EP4. The value of the Simpson indices did not have correlation dependence on the stage of recreational transformation.

No indices of diversity of avifauna had correlation dependence on the stage of recreational transformation and unity of fluctuation. Almost all indices indicated an increase in species richness in EP2 compared to EP1. Shannon and Simpson indices showed a slight decrease in the diversity with a further increase in the recreational transformation of EPs. Menchinick and Margalef indices showed a decrease in diversity in EP3 and increase in diversity in EP4.

Comparative evaluation of indices of diversity of phytocoenoses and avifauna in natural and semi-natural forests on recreational transformation gradient showed that human activities equally lead to the violation of composition of plants and birds communities. However, the absence of tendencies in the values of the indices of diversity for the ornithocomponent of forest ecosystem was explained by the fact that the evolution of each communities of birds passed independently of each other. The second reason was related to the mobility of birds and their need for visiting neighbouring habitats and, accordingly, the exchange of individuals between them. The third reason for the absence of synchronisation of changes in the spe-

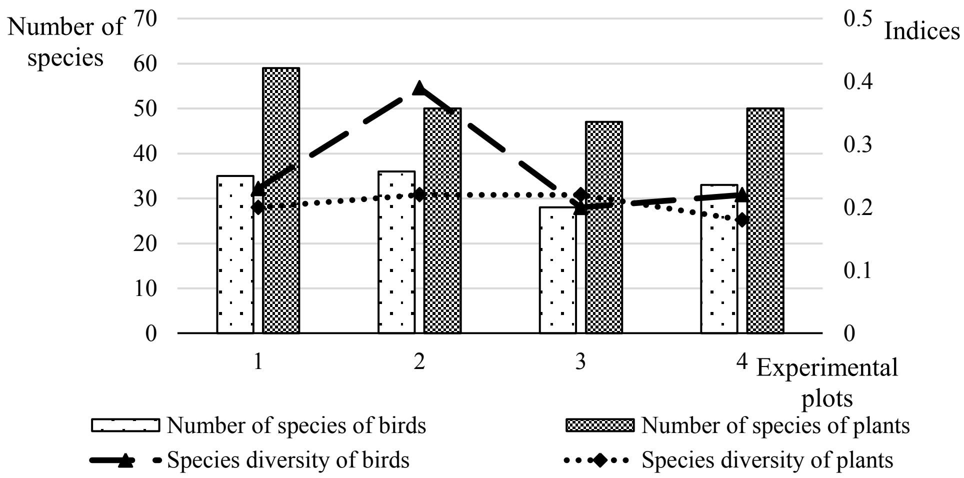


Fig. 8. Species richness of birds and plants communities.

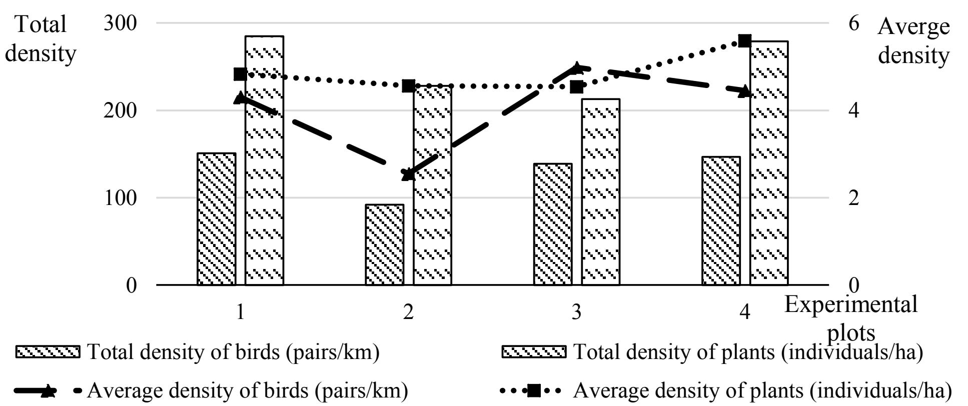


Fig. 9. Density of birds and plants communities.

cies diversity of birds in different communities, in our opinion, was that the adaptation of bird groups to anthropogenic transformations, in contrast to the adaptation of plants, passed through the serai communities. Consequently, it can be concluded that the response of the birds communities to changes in the plants communities requires additional time.

Dominance indices

The assessment of dominance indices showed that the level of dominance for plants and birds communities was almost the same for all the EPs (Fig. 11). The highest values of the Simp-

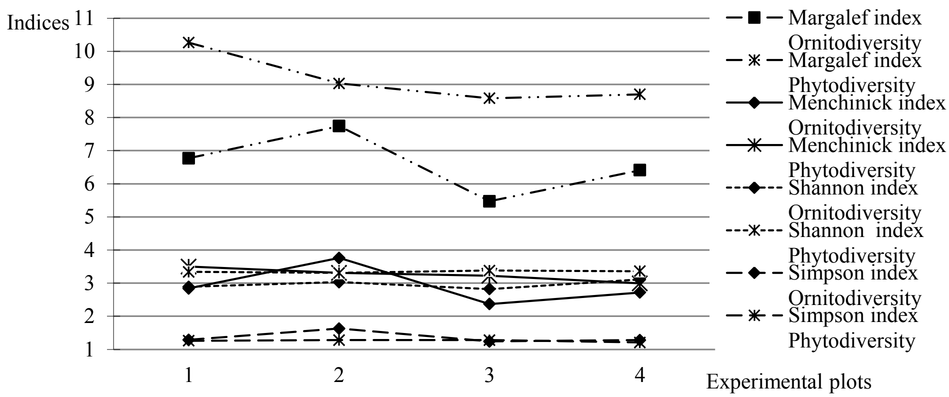


Fig. 10. The comparison of the trends of species diversity indices of plants and birds communities in the experimental plots.

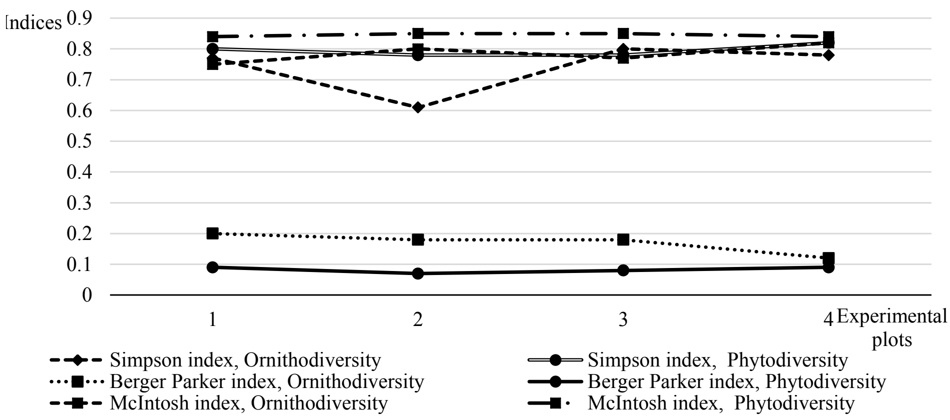


Fig. 11. The comparison of the trends of species dominance indices of plants and birds communities in the experimental plots.

son index (0.82) for plant communities were recorded in intensive-transformed EP4. This indicated that the ecological conditions were favourable for some species of plants (*Dactylis glomerata*, *Galinsoga parviflora* Cav., *Sanguisorba annua* (L.) Cass, *Taraxacum officinale* F.H. Wigg and others) in the intensive recreational transformation territory (EP4). Forest species of plants were more depressed. The values of the McIntosh dominance index were the maximum in EP2 and EP3. The values of the Berger–Parker index were minimal in these EPs.

The indices of dominance for bird communities did not show the unity of fluctuations. Only the Berger–Parker index had the most stable values of dominance. It gradually decreased from EP1 to EP4. The Berger–Parker index showed a slight decrease in the pressure of dominant species, especially in the intensive-transformed EP4. This trend was also confirmed by graphs of the curves of the ranking of the relative number of birds species in the communities (Fig. 11). The Simpson index showed a significant decrease in the pressure of dominant species in EP2 with a gradual increase. The McIntosh index gave us the opposite picture: a slight increase in the pressure of dominant species in EP2 and EP4, with a decreasing pressure in EP3.

In general, the assessment of dominance indices for plants and birds communities has showed that the curves of the dominance plant community's indexes had less differences than that of dominance bird community's indexes and also were not synchronised with the recreational transformation gradient.

Evenness indices

Evenness indices of vegetation layer and ornithocommunity demonstrated a slight increase in the values on the gradient of recreational transformation of the EPs (Fig. 12). Ranked curves of the species composition of birds showed similarities in data results of all the EPs. Evenness indices of ornithocommunity demonstrated balanced equitability of birds in EP4

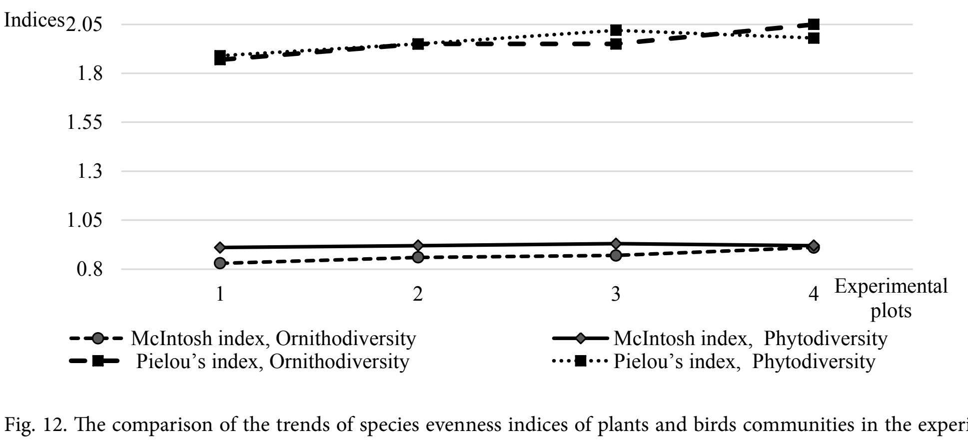
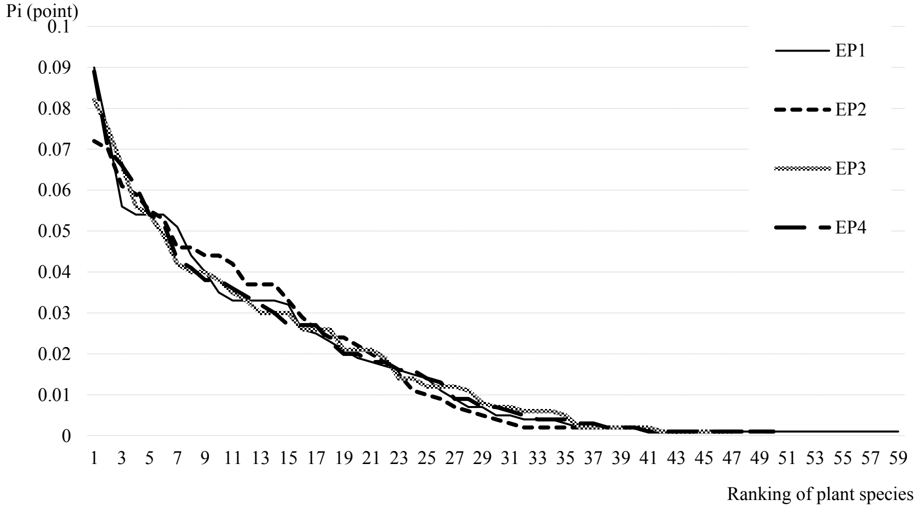
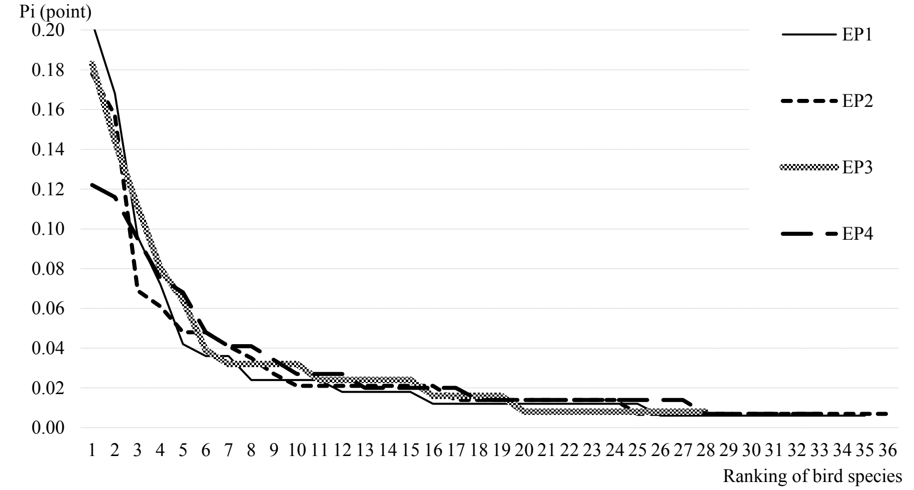


Fig. 12. The comparison of the trends of species evenness indices of plants and birds communities in the experimental plots.

(Fig. 13b). Significant difference was recorded for dominant species. In particular, the significant difference in the number of dominant species and subdominant common species was detected in EP4 compared to others EPs. The result of the ranked curves analysis confirmed the trend shown by the Berger–Parker index on the pressure of the dominant species (Fig. 13b).



(a)



(b)

Fig. 13. Evenness of species in (a) plant communities and (b) feeding birds in the experimental plots.

This analysis was due to the fact that the formation of birds communities has been completed in EP4, because biotopes have been transformed for a long time and the birds have already adapted to anthropogenic impact. The formation of birds communities has begun recently and the birds have not yet been adapted to the impact in less-transformed natural and semi-natural forests of Kyiv. Such communities were less balanced and more responsive to human interference.

The evenness of species of phytocommunity was balanced. The similarity of the evenness of relative number of plants species was noted for all the EPs (Fig. 13a). Ranked curves showed the best state of dominance of plant communities in EP1 and EP2, where the highest number of species were detected. Thus, the analysis of biodiversity indices showed a discrepancy between the reaction of plants communities and birds communities of natural and semi-natural forests to the recreational transformation by most of the indices.

The Berger–Parker index has demonstrated the similarity in the fluctuations of dominance in the communities, and the Shannon and Simpson indices demonstrated the similarity in the diversity. However, the values of the Shannon and Simpson indices did not depend on the gradient of recreational transformation of forests.

Assessment of other indicators of communities

Most of the tree canopies nesters was recorded in EP4, where the lowest developed classes of trees (III–V) and the highest state index were found (Fig. 14). Most of the ground nesters was registered in EP1, where the highest developed classes of trees (I–II) and the lowest state index were found. The insignificant decrease in the relative ratio (abundance) of tree hollow nesters was recorded in the investigated EPs. An increase in the ratio of bird's tree canopies nesters depending on the gradient of transformation was also established. The highest abun-

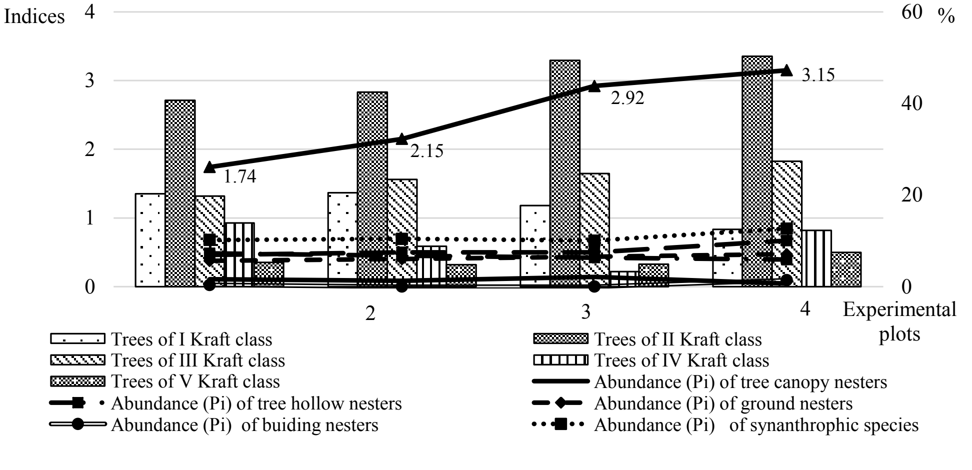


Fig. 14. The share of various ecological groups of birds and vitality and health compositions of trees.

dance of synanthropic species (0.845) was in EP4. The ratio of other ecological groups of birds by nesting stations was fluctuated, but the interrelation with the gradient of recreational transformation was not established.

It should be noted separately that the increase in the relative number of ground nesters was recorded in the moderate-transformed EP3. This was due to the fact that visitors were raced cyclocross and motocross, reconstructed historical events and collected medicinal herbs in EP3. Consequently, only a fraction of the territory of EP3 was essentially transformed. Another fraction of the territory of EP3 had a lot of microstations suitable for the comfortable existence of birds.

Discussion

Human activity leads to the disappearance of most species of birds, which are typical for the indigenous forests of the Forest-Steppe, the intensive expansion of birds of meadow and shrubby phytocoenoses (Blinkova, Shupova, 2017). The impact of forestry activity on avifauna depends on the intensity of extraction of timber (Gabbe et al., 2002; Rodewald, Abrams, 2002; Šalek et al., 2010; Pereira et al., 2014; Bergner et al., 2015). The change of mixed forests in forest monoculture leads to a decrease in the species richness of birds, density of the ornithocommunity and its biomass by one-third, indicating a reduction in the volume of ecological niches (Fischer et al., 2007; Gardner et al., 2008; Whelan et al., 2008; Felton et al., 2016). Human factors such as firewood and fodder collection, timber extraction and grazing bring about subtle changes in the habitats available to birds. The authors succeeded in identifying explainable relationships between bird components and habitat types. Different guilds showed preferences for diverse habitats, suggesting that they are directly related to habitat conditions. Moreover, significant relationships between bird species diversity and richness and tree species diversity and richness added more convincing relationships with the overall biodiversity (Chettri et al., 2005).

Conventional management involves the removal of a substantial part of the understory in order to prevent establishment and spread of wildfires. These practices might have negative consequences for birds that depend on shrubs for breeding and foraging, which showed that it was possible to keep breeding species in managed forests as long as sufficient shrub layer was retained in the understory (Camprodon, Brotons, 2006; Heyman, 2010). The analysis of the ecological structure of the birds communities showed that forests are more abundant in species associated with closed forest habitats than other plant associations (Domokos E., Domokos J., 2016). Recent studies suggest that birds communities are influenced by woodland vegetation cover at both the patch and the landscape scales and that these relationships are consistent over time (Ikin et al., 2014).

The analytical results showed that the changes in the species number and density of bird as well as the formation of birds communities follow the changes in forest type and the total foliage. Both the number of bird species and their density decreased with the decrease in total foliage. The similarity in bird community was very low at the breeding time. In the same classification of cluster, no similarity was higher than 0.65, which indicated that the composition of species had a great difference between all the birds communities. The bird's breeding density was closely related to forest growth stage. From the bare grassland ecosystem to climax ecosystem, the density of bird species showed a gradually increasing trend (Wen et al., 2002).

The degradation of natural habitats is a significant factor affecting the fauna in inhabited localities (Tomiałojc, 2007; Grimm et al., 2008; Møller et al., 2015). The authors prove that the mosaic of landscapes increases the species richness of birds. A highly fragmented habitat leads to a decrease in the populations of limited species that have large nesting station and increase the risk of disappearing of these populations (Tews et al., 2004; Sekercioğlu, 2006; Giltena et al., 2007; Moreno-Rueda, Pizzaro, 2009; Šalek et al., 2011; Robles et al., 2012; Domokos E., Domokos J., 2016).

In this study, the natural and semi-natural forests remaining on the territory of the Kyiv are far from each other. The exchange of individuals between communities of birds is limited. These common species are typical for the region: *Columba palumbus, Jynx torquilla, Anthus trivialis, Lanius collurio, L. minor, Garrulus glandarius, Pica pica, Sylvia borin, Parus caeruleus, P. montanus*, *Chloris chloris* and *Carduelis carduelis*. Such fragmentation of the forest landscape leads to separated co-evolutionary process of birds communities and the absence of general communities of birds in all forests of the city. Ecological conditions are different for each EPs; therefore, nesting and feeding stations are suitable only to isolated species of communities. *Columba livia, Apus apus, Passer domesticus* and *P. montanus* are dominant nesting species, and *Sturnus vulgaris, Corvus cornix, Phoenicurus ochruros, Parus major, P. caeruleus, Chloris chloris* and *Carduelis carduelis* are common species of residential district of Kyiv (Shupova, 2014). The exchange of individuals between communities of these bird species is possible in the forests and residential districts of the city.

The authors indicate that streetscape vegetation plays an important role in influencing urban bird communities, with streetscapes dominated by native plants supporting communities with high native species richness and abundance, whilst exotic and newly developed streetscapes support more introduced bird species and fewer native bird species. Research has also revealed that urban remnants are likely to support more native bird species. Vegetation structure and quality do not appear to be as important a driver as remnant size in determining the richness of native birds communities (White et al., 2009). An analysis of the ecological and species compositions has shown that with insufficient number of nesting woodpeckers in communities, tree hollow nesters will be limited by the number of suitable nesting stations (Angelstam, Mikusinski, 1994; Carlson et al., 1998; Mikusinski et al., 2001; Virkkala, 2006; Woodley et al., 2006; Robles et al., 2011, 2012).

Our research showed that the total density of woodpeckers and their species composition were important. Nesting of only 2 species (*Dendrocopos major* and *D. medius*) with a high density had led to a significant increase in the density of *Sturnus vulgaris* in the communities of the most of the transformed forests. Nesting of *D. major* and *D. medius* also caused a change in the species composition and density of nesting birds of the genera *Ficedula* and *Parus*.

The authors point out that the communities of nesting birds gradually changes according to the transformation of habitats (Rodewald, Abrams, 2002). Trampling down leads to the transformation of the herbaceous cover, the destruction of shrubbery and the reduction in the proportion of birds ground nesters (Camprodon, Brotons, 2006; Heyman, 2010; Šalek et al., 2010). The authors showed that the dogs walking prevents the arrangement of nests and contributes to the reduction in the number of birds associated with the ground level (Shupova, 2017).

In our study, this conclusion is confirmed by the fact that the abundance of ground nesters was less in the forests located in the surroundings of residential districts of the city. The abundance of ground nesters was the highest in the forestland remote from residential districts by transport infrastructure, although biotope had moderate stage of recreational transformation.

The species richness of the birds communities varies according to the transformation of the habitats (Graham et al., 2014). The studies show disturbance of the species composition of birds depending on the recreational transformation of the biotope. Increasing the structural complexity of the forest ecosystem expands the range of nesting and feeding stations of birds (James, Wamer, 1982; Hinsley et al., 1995; Katsimanis et al., 2006).

Our data showed that most of the species richness and the number of nesting species were in the forest with medium stage of anthropogenic transformation. Species composition and the richness of avifauna is due to nesting species that are absent in the intensive-transformed forest (*Cuculus canorus, Anthus trivialis, Lanius minor, Hippolais icterina, Aegithalos caudatus*) and the presence of species from other biotopes (*Jynx torquilla* and *Emberiza citrinella*). The impact of pressure on birds communities is confirmed by the increase in the ratio of woody nesters. This indicates the redistribution of nesting stations in favour of the inaccessible place for a people. Birds have not been adapted to recreational impact, and compositions of ornithocommunities were less balanced in the weak-transformed forest.

The authors attribute this to the limited ability of birds to quickly adapt to dynamic conditions of existence and the development of gradual adaptation (Martin, Joron, 2003; Gill, 2006; Brockerhoff et al., 2008; Graham et al., 2014). The presence of synanthropic species in the birds communities makes it possible to detect the impact of urbanisation on the communities of natural and semi-natural forests (Chaplygina et al., 2016).

Our data also confirm the results of other authors. The nesting obligatory synanthropes (*Columba livia* and *Phoenicurus ochruros*) are observed in the most-transformed forest. *P. ochruros* is an alien species of even land of Ukraine. Nesting hemysynanthropes with natural populations were recorded in forest of weak stage of recreational transformation. Given that the components of the bird community used the elements of this landscape differently, the conservation of each element requires the application of different management strategies (Elisa, Schondube, 2015).

Notable differences also occurred with respect to the relative abundance of specific feeding guilds. The natural stands supported higher abundances of invertebrate feeders, omnivores and herbivores, whereas the mature production stands supported more granivores. These outcomes are likely to have arisen because of the increased diversity of forest environments encountered in the natural stands. More diverse forest environments provide increased foraging environments and microhabitats and thus increased opportunities for a wider range of bird species possessing distinctive feeding niches. These differences between the stand types surveyed, as well as their respective landscape setting, also have the capacity to affect the populations of avian predators (Felton et al., 2016). This dependence is also confirmed

T a b l e 6. Correlation matrix of diversity indices of plants and birds communities. Indices of horizontal heterogeneity of vegetation and vertical heterogeneity of vegetation are also shown.

Indices	N_1	P_1	DMr_1	DMn_1	Ds_1	H_1	d_1	U_1	λ_1	E_1	Us_1	N_2	P_2	DMr_2	DMn_2	Ds_2	H_2	d_2	U_2	λ_2	E_2	Us_2	IHH	IVH
N_1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P_1	0.74	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DMr_1	**0.97**	0.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DMn_1	**0.70**	0.04	**0.82**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ds_1	−0.08	−0.73	0.31	**0.86**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
H_1	−0.35	−0.08	0.54	**0.68**	0.59	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
d_1	0.51	**0.82**	−0.12	0.35	−0.71	0.49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
U_1	−0.66	−0.98	−0.83	0.05	**0.78**	−0.09	**−0.90**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
λ_1	0.30	0.86	−0.46	−0.32	−0.97	0.20	**0.81**	0.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E_1	−0.94	−0.65	−0.91	−0.72	−0.43	0.73	−0.25	0.53	0.19	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Us_1	−0.94	−0.82	−0.69	−0.53	0.25	0.54	−0.31	0.75	−0.42	**0.96**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
N_2	0.59	0.49	**0.78**	0.36	0.11	0.34	−0.09	−0.32	0.19	−0.80	−0.82	-	-	-	-	-	-	-	-	-	-	-	-	-
P_2	−0.28	0.58	0.24	−0.10	−0.52	**0.71**	**0.84**	−0.70	0.61	−0.04	0.08	−0.41	-	-	-	-		-	-	-	-	-	-	-
DMr_2	0.34	0.16	0.36	0.32	0.10	−0.98	−0.42	0.01	−0.07	−0.62	−0.57	**0.93**	−0.69	-	-	-	-	-	-	-	-	-	-	-
DMn_2	0.09	−0.10	0.16	0.26	0.28	−0.96	−0.65	0.28	−0.28	−0.40	−0.32	**0.81**	−0.86	0.96	-	-	-	-	-	-	-	-	-	-
Ds_2	−0.09	−0.31	−0.01	0.20	0.39	−0.89	−0.80	0.48	−0.44	−0.22	−0.11	**0.65**	−0.95	0.87	0.97	-	-	-	-	-	-	-	-	-
H_2	−0.10	0.38	−0.24	−0.57	−0.68	−0.40	0.02	−0.32	0.59	−0.05	−0.21	0.54	−0.26	0.53	0.47	0.40	-	-	-	-	-	-	-	-
d_2	0.44	−0.26	0.62	**0.94**	**0.84**	−0.29	0.30	0.33	−0.70	−0.45	−0.23	0.11	−0.17	0.15	0.17	0.39	−0.75	-	-	-	-	-	-	-
U_2	−0.56	0.01	−0.67	−0.83	−0.56	−0.12	−0.16	**0.98**	0.39	0.42	0.28	0.15	−0.33	0.24	0.30	0.33	0.88	−0.86	-	-	-	-	-	-
λ_2	0.06	0.31	−0.01	−0.22	−0.39	**0.90**	0.80	−0.46	0.43	0.26	0.14	−0.67	0.94	−0.88	−0.97	−0.99	−0.36	−0.19	−0.33	-	-	-	-	-
E_2	−0.65	0.01	−0.78	−0.98	−0.67	0.28	0.07	−0.07	0.50	**0.63**	0.44	−0.20	−0.01	−0.16	−0.10	−0.05	0.70	−0.86	0.91	0.08	-	-	-	-
Us_2	−0.68	−0.01	−0.80	−0.99	−0.67	0.39	0.15	−0.08	0.50	**0.78**	0.49	−0.31	0.08	−0.28	−0.22	−0.17	0.68	−0.95	0.88	0.19	0.99	-	-	-
IHH	0.11	−0.58	0.30	**0.78**	**0.98**	**0.98**	−0.62	0.66	−0.91	0.18	0.06	0.36	0.51	0.18	0.30	0.38	0.68	**0.92**	−0.66	−0.39	−0.70	−0.80	-	-
IVH	**0.86**	0.40	**0.94**	**0.96**	0.43	**0.79**	0.06	−0.19	−0.22	−0.87	−0.74	**0.82**	0.21	0.40	**0.77**	0.17	**0.70**	**0.81**	0.01	0.18	−0.92	−0.94	0.69	-

in our study: only 1 species of predators has been observed – synanthropic species, *Falco tinnunculus*. Pereira et al. (2014) showed that insectivorous warblers were more abundant in dense oak stands with a more extensive cover of understory vegetation (0.9–1.0). Insectivorous, ground-nesting passerines apart from being constrained by lack of suitable nest sites might also face a lack of food resources, which limits its distribution in stands. The relative abundance of birds that feed on stands increases with the cover of understory vegetation (less than 0.9). Birds from agro-forest open habitats increased in abundance in cleared and thinned oak forests, remaining less frequent in denser forests. However, if ligneous vegetation is dense enough, clearing of the vegetation may have negligible effects on birds. If the undergrowth clearing is accompanied by selective thinning, the combined effects of these 2 factors on the bird community appear more intense. This management practice diminishes the abundance of undergrowth bird species and also the thinning induces changes in the composition of the tree-canopy birds and benefits other species associated with agro-forest open habitats (Shirihai et al., 2001).

In our studies, the density of nesting birds of the Piciformes and Passeriformes that feed on the tree stands varied with the gradient of transformation as follows: 56.2–26.5–38.8–28.0 pairs/km. The stand density reduced from 0.5 to 0.8, and the average number of growth too was reduced from 6.87 to 2.3. The distance between the trees increased. Many species of woodpeckers specialise in the use of forest resources and depend on trees to find food and nesting (Mikusinski et al., 2001; Robles et al., 2007; Ciudad et al., 2009; Robles et al., 2012; Touihri et al., 2014). In particular, *Dendrocopos medius* is an indicator of broad-leaved forests (Robles et al., 2007; Roberge, Angelstam, 2006). In our research, the woodpeckers marked almost everywhere in the natural and semi-natural forests of the megalopolis. Quantitative indices of secondary tree hollow nesters are not closely related to the number of woodpeckers of urban ecosystems in comparison with natural forests through forestry work, which includes artificial nesting for birds (Blinkova, Shupova, 2017).

The assessment of correlations between parameters of plant communities and birds communities confirmed significant relationship between the index of vertical heterogeneity and the number of bird species ($r = 0.82$; $p<0.01$). However, significant relationship between the index of vertical heterogeneity and nesting density was not confirmed in our results ($r = 0.21$) (Table 6). A relationship between IVH and the Menchinick index of diversity ($r = 0.74$; $p < 0.01$) was also noted ($r = 0.77$; $p<0.01$). A relationship between IVH and the Shannon index of diversity ($r = 0.70$; $p<0.01$) was slightly weaker. It should be noted that the correlation between IVH and Berger–Parker dominance index ($r = 0.81$; $p<0.01$) was recorded for the first time in this study. This relationship was not confirmed in other articles. The obtained data showed a relationship between the multi-storeyed vertical composition of the forest and the diversity of birds.

The correlation between index of horizontal heterogeneity and Berger–Parker dominance index ($r = 0.81$; $p<0.01$) was confirmed in forests of megalopolis. The relationship between density of nesting and IHH was not confirmed, but it was slightly closer ($r = 0.51$) compared to IVH. Thus, our studies confirmed the relationship between the distribution of birds and the IHH of the forest. A relationship between the Menchinick index of plant diversity and the number of species of birds ($r = 0.78$; $p <0.01$) was observed. Close relationships between

Shannon index of diversity for plant communities and the total density of birds (r = 0.71; p<0.01) and Simpson dominance index for plant communities and the total density of birds (r = 0.84; p<0.01) were also established. The Simpson dominance index for birds communities revealed a relationship with the floristic indices diversity by Menchinick (r = 0.94; p <0.005) and the Simpson (r = 0.84; p<0.01). The presence of a correlation between the bird's species diversity and the floristic richness is evidenced by the obtained data. In other studies, no vegetation variable explained bird's species richness or diversity. Total foliage volume and foliage height diversity were significantly correlated with bird's species diversity in the no forest sites but not in the forested areas. However, foliage height diversity significantly explained the variation in bird's density and species richness in the forest sites (Chamberlain et al., 2007). The results of studies found strong relationships between vegetation associations and landscape position. These patterns were related to disturbance and stress from natural and human processes. Avian populations were strongly related to the vegetation patterns of deciduous cover, but there was not as strong a correspondence with landscape position and the levels of disturbance and stress (Milne, 2003).

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Appendix 1. Conservation status of birds in the experimental plots.

Species	EP1	EP2	EP3	EP4	Protection category
Falco tinnunculus	0	0	0	1	Bk2; Bo2; W 2; K
Columba palumbus	0	1.3	1.1	4	–
Columba livia	0	0	0	7	Bk3
Cuculus canorus	0.9	0.6	0	0	Bk3
Caprimulgus europaeus	1.8	0	1.1	0	Bk2
Jynx torquilla	0	0.6	0	1	Bk2
Dryocopus martius	1.8	0	1.1	0	Bk2; K
Dendrocopos major	1.8	1.3	2.2	5	Bk2
Dendrocopos medius	3.6	1.9	0	2	Bk2
Dendrocopos minor	2.7	0.6	1.1	0	Bk2
Anthus trivialis	0.9	0.6	3.3	0	Bk2
Lanius collurio	0	0	3.3	0	Bk2
Lanius minor	0	0.6	0	0	Bk2
Oriolus oriolus	3.6	1.9	4.4	4	Bk2
Sturnus vulgaris	0.9	4.4	0	18	–
Garrulus glandarius	0	0	1.1	1	–
Pica pica	0	0	0	3	–
Corvus cornix	2.7	1.3	1.1	4	–
Corvus corax	0	0.6	0	0	Bk3
Troglodytes troglodytes	0.9	0.6	5.5	3	Bk2
Hippolais icterina	0.9	1.9	0	0	Bk2
Sylvia atricapilla	0.9	1.3	2.2	0	Bk2
Sylvia borin	0	0	0	1	Bk2
Phylloscopus collybita	6.4	1.9	4.4	2	Bk2
Phylloscopus sibilatrix	0.9	1.3	2.2	2	Bk2
Ficedula hypoleuca	1.8	0.6	1.1	0	Bk2; Bo2
Ficedula albicollis	1.8	1.9	1.1	2	Bk2; Bo2
Ficedula parva	0.9	0	0	0	Bk2; Bo2
Muscicapa striata	1.8	1.9	3.3	2	Bk2; Bo2
Phoenicurus ochruros	0	0	0	2	Bk2; Bo2
Erithacus rubecula	5.5	5.6	11.1	6	Bk2; Bo2
Luscinia luscinia	5.5	3.8	3.3	3	Bk2; Bo2
Turdus pilaris	0	3.2	4.4	17	Bk3; Bo2
Turdus merula	14.5	6.3	15.5	10	Bk3; Bo2
Turdus philomelos	3.6	1.9	3.3	2	Bk3; Bo2
Aegithalos caudatus	1.8	0.6	0	0	Bk2
Parus palustris	1.8	0	2.2	0	Bk2
Parus ater	1.8	1.3	0	1	Bk2
Parus caeruleus	2.7	1.3	0	2	Bk2
Parus major	30.9	16.3	25.5	14	Bk2
Sitta europaea	10.9	2.5	8.9	2	Bk2
Certhia familiaris	2.7	1.3	1.1	1	Bk2
Passer montanus	3.6	0	0	6	Bk3
Fringilla coelebs	25.5	14.4	20	11	Bk3
Chloris chloris	0.9	0.6	0	3	Bk2
Carduelis carduelis	1.8	0.6	0	0	Bk2
Acanthis cannabina	0	0	0	3	Bk2
Coccothraustes coccothraustes	0.9	4.4	4.4	2	Bk2
Emberiza citrinella	0	0.6	0	0	Bk2

Bk2, Bk3, categories of The Bern Convention; Bo2, categories of The Bonn Convention; W2, categories of Convention on International Trade in Endangered Species of Wild Fauna and Flora; K, threatened species for Kyiv region (Konishchuk et al., 2012).

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MAPPING THE RISK OF FOREST FIRES IN ALGERIA: APPLICATION OF THE FOREST OF GUETARNIA IN WESTERN ALGERIA

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Abstract

Belgherbi B., Benabdeli K., Mostefai K.: Mapping the risk forest fires in Algeria: Application of the forest of Guetarnia in Western Algeria. Ekológia (Bratislava), Vol. 37, No. 3, p. 289–300, 2018.

The methods applied in Algeria for the prevention and fight against the fires remain fairly traditional and have proved to be ineffective in reducing the disastrous impact of this phenomenon. However, the aim of this work is to analyse a forest ecosystem that is fairly representative of the whole of the forests in Algeria, on plan risk and vulnerability of the environment for a better control of risk. *Using modern geomatics techniques* to map the degree of risk of fires and analysis the space: *like satellite* imagery spatial data and Geographic Information Systems (GIS).The Guetarnia forest in western Algeria has been retained; seven thematic maps have been developed and have helped to develop a sensitivity map to depict the fire risk.

Key words: forest fires, map risk, remote sensing, GIS, Guetarnia (Algeria).

Introduction

Each year, several million hectares were burnt at the global scale in the Mediterranean basin. It is estimated that 6000,000 to 8000,000 ha are annually destroyed by fire, especially in the countries of the northern shore of the Mediterranean (Rowell, Moore, 2000; Carrega, 2008; Hansen et al., 2013). However, the forest of Algeria is typically Mediterranean terms of its climate, terrain, composition and structure; it is very sensitive to fire. Over the centuries, it has witnessed various degradations, while they were flourishing at the Carthage and Roman eras, and even after the invasion of Arabs (De Ribbe, 1866; Trollard, 1893). The forest heritage of Algeria is in perpetual degradation; it is an area estimated at 5 million ha during the colonial period (Boudy, 1948) that has extended to 1,492,000 ha (FAO, 2013). The forest area was reduced, during the colonial period (1830–1962), to 2,400,000 ha (Boudy, 1948; Berchiche, 1968; Sari, 1978; Rebai, 1983). An average of 18,182 ha is burned annually.

In the MENA (Middle East and North Africa), Algeria represents the country most affected by forest fires in percentage of travelled surface. For a country highly threatened by desertification, it has avery low rate of forestation estimated at 1.76% (FOSA, 2000; Nedjraoui, 2003). The analysis of data from the Directorate General of Forests (DGF) pointed out that during the period 1963–2014, the area affected by forest fires was in the order of 1,770,800 ha, or an average of area travelled per year of 35,000 ha/year (DGF, 2014).

The current situation reflects Algeria's weak ability to control the forest fires phenomenon and this is due to several reasons: the lack of a database relating to fire, ignorance of the causes, lack of silvicultural work, aging infrastructure that is most of the time archaic and dilapidated, an absence of vision of management even in the short term; to this should be added a technical staff that is far from any progress in terms of training and current techniques for combating the fires of forests.

The Guetarnia forest is a fair representative of the forests of the country; it is semi-arid, has registered area of 624,286 ha, was burned during the period from 1903 to 1922, and has an annual average of area covered by the fire of 31.02 ha/year. The analysis of the current period (1981–2014), allows seeing that the average of area burned annually is 250 ha on a total of 7,127,707 ha. The resurgence of fires is clearly confirmed since the annual mean surface area burned has increased from 31 to 250 ha.

Furthermore, the risk assessment of forest fires has been the main topic of several research papers, and fire is the most redoubtable and most devastating factor that can cause damage to the forests of Algeria (Leutreuch, 1982; Benabdeli, 1996; Madoui, 2002; Arafa, 2008; Terras et al., 2008; Khader et al., 2009; Mohamed et al., 2011; Berrichi et al., 2013; Borsali et al., 2014; Meddour et al., 2014; Meddour, 2015). Despite this worrying fact; there is no national strategy focused on mapping the fire risk in order to put in place a plan of prevention is business. Finally, the objective of this study is to use the modern technique geomatics, (GIS), in order to assess the risk of forest fires on the one hand and to put at the disposal of managers a set of adapters that can be used in order to propose a solution for the prevention and management of the forest fire risk. The Guetarnia forest has been chosen, as it brings together the majority of the ecological characteristics and socio-economic of forest ecosystems, to achieve the objectives of the environment for a better control of risk.

Material and methods

Ecological characterization of Guetarnia forest

The forest of Guetarnia is located in the north-westerern Algerian region (Fig. 1) and is part of the mountains of Beni-Chougrane. Guetarnia is localized between longitude 0°00 and 0°30'E and latitude 35°00' N and 35°30' N with an area of 10,140.12 ha, and also focused between two wilayas, wilaya of Mascara with a surface area of 2,818.82 ha and wilaya of Sidi-Belabbes with 7,321.30 ha. The forest of Guetarnia presents a rugged topography of mountains and foothills with altitude soscillating between 411.8 and 813 m inducing a class of slope between 15 and 30% with more than 55% (Belgherbi, 2002).

The facies lithology is represented by a substrate of origin Miocene and Cretaceous constituted by elements generally soft and eroded. The substratum Miocene is covered everywhere by the quaternary formations: calcareous crusts, sandy clays and sands. The soils are sandy clay to sandy (Dalloni, 1940, 1953). This type of ground limestone, generally low depth (between 30 and 40 cm), belonging to the class of redziniferes soils and calcareous brown (Dalloni, 1940, 1953; Belgherbi, 2002).

The forest falls within the bioclimatic floor semi-arid to temperate variant with an average annual precipitation of 350 mm. Two periods characterize this region: a cold season between November and April, recording the minimum of less than 3 °C and a hot season from May to October with the maxima of 35 °C.

The vegetation, Mediterranean-type sclerophyllous, is characterized by arecovery of the order of 45% with a composition dominated by three species: the *Pinus halepensis* Mill, *Tetraclinis articulate* Vahl and *Quercus rotundifolia* L. The first two species occupy more than 65% of the acreage and are pyrophytes with a high combustibility and flammability. The stratum shrubby and bushy is represented primarily by the *Rosmarinus*, *Phillyrea* and the *Chamaerops humilis* (Souidi et al., 2010).

Methodology

The establishments of the map of vulnerability of forests to fires in fact appeal to the application of a model established by (Dagorne, Duche, 1994) and tested on the mountainous forest of the Mediterranean region. The different steps of the methodology adopted throughout in this work are represented by the flowchart synthesized in Fig. 2.

The basic data for these formulas, exploited by a series of specialized software, allow the establishment of different maps (layers of useful information); these last few are going to be the subject of superposition in order to put in place the map from the fire risk. The tools implemented for the development of the map of the fire risk are ENVI 3.4 and MAPINFO 7.0. The latter has been used for the establishment of the digital terrain model (DTM) and for obtaining the map of slopes, exhibitions and the topomorphology.

The ENVI (Environment for Visualising Images) has been used to process the images, enabling the visualization and analysis of data. Its functionality resides in the fact that it contains a library of algorithms, includes functions for transformation of data, filter functions as well as functions of classification.

Fire risk modelling

To evaluate the fire risk, it is necessary to model each element of risk, three main factors for the assessment of risk of forest fires such as the fuel, the topomorphology and human activities. The index that has interested us in this work is given by formula (1) proposed by (Dagorne, Duche, 1994). The principle of risk estimated by this formula is based on the product of hazard and vulnerability.

$$IR = 5.IC + 2.IH + IM \qquad (1)$$

where: IR is Risk index; IC is index of combustibility; IM is Topo-morphological index; IH is index of human activities.

Based on the principle of weighted sum, this index is designed as a model assigning each parameter a weighting coefficient based on its influence on the spread of fire.

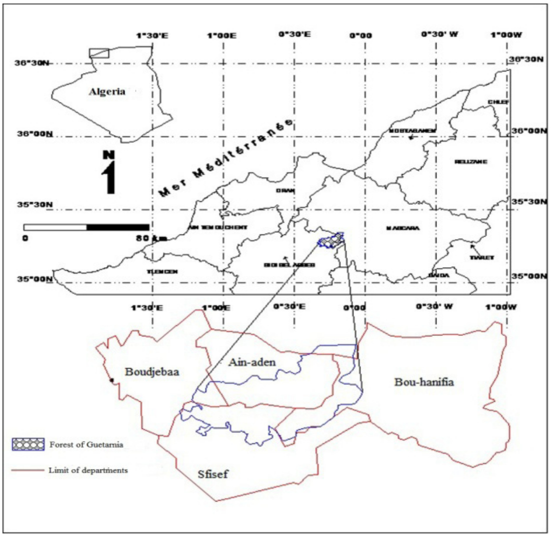

Fig. 1. Location of the forest of Guetarnia.

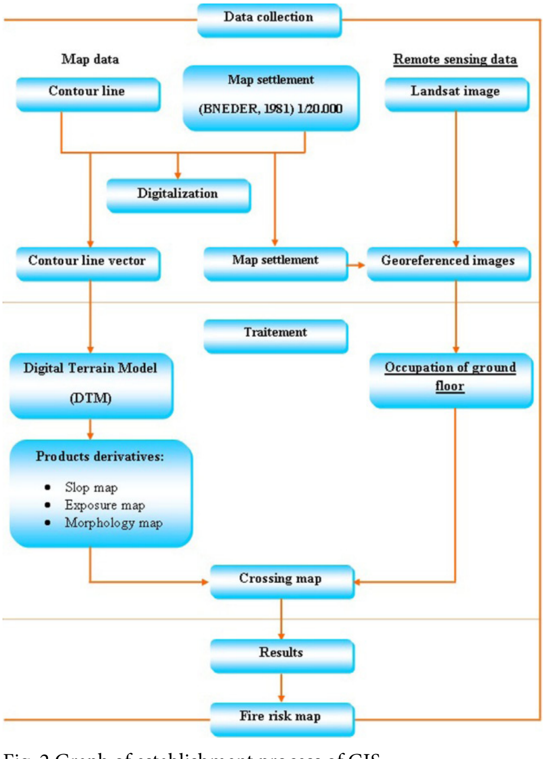

Fig. 2.Graph of establishment process of GIS.

The characterization of this index is based on the spatial variability of the risk of fire whose determination is the outcome of the physical parameters involved in the model chosen (Keaneet al., 2010).

In the proposed model, index topo-morphologic (IM), three topographic parameters were involved: slope, exposure and altitude. These settings are deducted from the digital terrain model (D.T.M.) in the region. This index is expressed by the following relationship:

$$IM = 3p + e.m \, . \qquad (2)$$

where: p is slope; m represents morphology of area; e is exposure.

To evaluate the index of combustibility (IC), the method proposed by (Putri et al., 2016) to estimate the potential severity of a fire starting in a forest stand determines has been retained. This method consists of, in the development of a model, empirical data, based on the experience of the fire brigade to weight the terms of a mathematical expression whose parameters are from a standardized description of the vegetation (Keane et al., 2010).

Among the parameters reflecting the susceptibility of the vegetation to fire is the type of fuel available (horizontal stratification and vertical), that is, the phytomasse. This is an important factor in the emergence and spread of fires (Dagorne, Castec, 1992; Mariel, 1998).

The index of combustibility or intensity index of potential fire is expressed by the following relationship:

$$IC = 2.4BV(E_1 + E_2 - 7.18) + 39 \qquad (3)$$

where: BV is the biovolume of the plant formation; E_1 is the note of combustibility for wood senior; E_2 is the note of combustibility for the wood bottom or herbaceous plants.

The biovolume of the vegetation formation is obtained by adding the rate of recovery of each of the 4 strata of vegetation (wood senior, wood bottom, herbaceous and litter) to which we add the rate of recovery of snags and dead wood, if there is a place. Each of these recovery rates is 0 (absence of stratum) and 10 (stratum forming a closed canopy); the biovolume is therefore between 0 and 50. The notes of calorie intensity are included between 1 and 8 for the two dominant species: E_1 for wood senior and E_2 for wood bottom or herbaceous.

Results

The digital terrain model (DTM)

The forest of Guetarnia presents a rugged topography with a mountainous area located in the south of the forest and stretching toward the north-east. The lands at low altitude are localized in the northern part of the forest. The mountainous part has an altitude that varies between 650 and 813 m; it is dominant at the level of Sidi Bel-Abbes at the level of the canton of Ain Aden and Sfisef (Fig. 3).

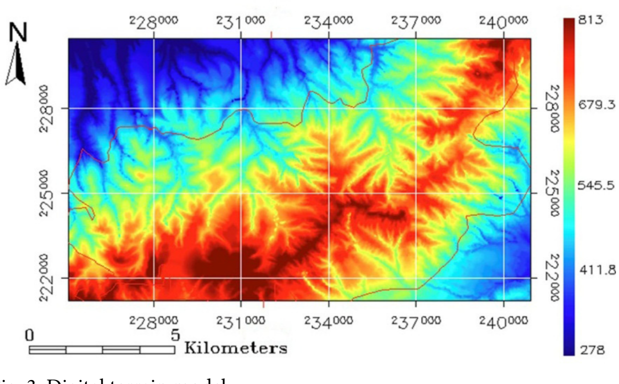

Fig. 3. Digital terrain model.

The digital terrain model (DTM) allows you to derive slope, exposure, and topomorphology; these derivatives are used to calculate the index topomorphologic.

Map of exposure

The forest massif of Guetarnia presents three major classes of exposure in relation with the prevailing winds, as listed in Table 1.

The exposure "'*e*'" reflects the situation of the catchment area in relation to the prevailing winds and to the solar radiation. The map of the exposure of the forest is represented by the Fig. 4 below.

T a b l e 1. Frequency of exposures.

Meaning	Area (ha)	Percentage (%)
NE—E—SE—S	4,053.37	39.97
S—SW—W—NW	3,992.66	39.37
NW—N—NE	2,094.59	20.65
Total	**10,140.12**	**100**

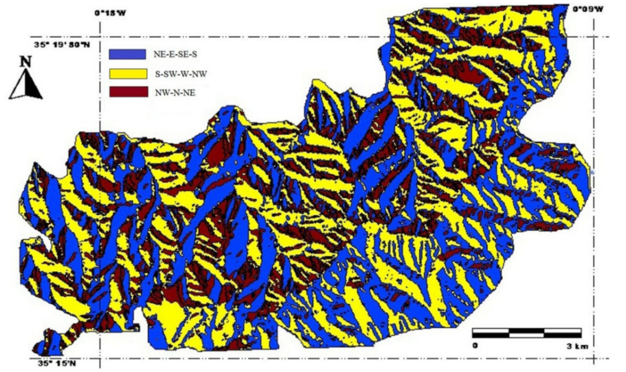

Fig. 4. Map of exposure.

Map of topomorphology

The position in the catchment area or topomorphology "'*m*'" weighted the fire intensity as a function of the position in the terrain. Topomorphology was adopted in preference to altimetry. To do this, four main sets of topomorphologic were retained in (Table 2; Fig. 5). The four classes define the topographic situations increasingly unfavourable for the fight (Belgherbi, 2002).

The forest of Guetarnia is represented by the senior foothills on an area of 6,510.36 ha (62.20%); the fraction mountain represents only an area of 1,433.05 ha (14.13%).

T a b l e 2. Frequency of the topomorphology.

Meaning	Area (ha)	Percentage (%)
P< 3% (**Plain**)	83.93	0.83
P(3—12.5%) (**Lower piedmont**)	2,112.78	20.84
P (12.5—25%)(**High piedmont**)	6,510.36	64.20
P> 25% (**Mountain**)	1,433.05	14.13
Total	**10,140.12**	**100**

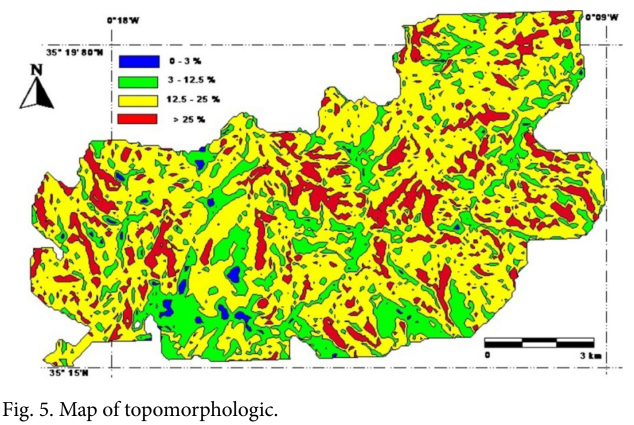

Fig. 5. Map of topomorphologic.

Map of slopes

The slope "'*p*'" is a factor of the acceleration of fire front. It is classified into four classes.

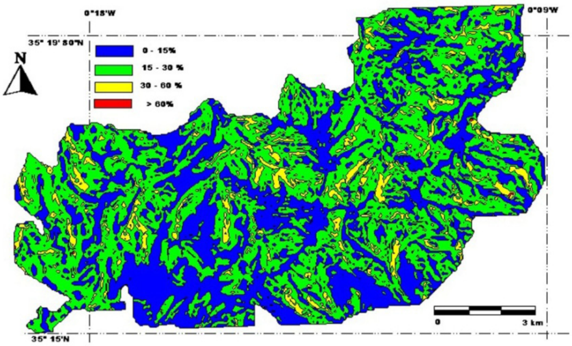

Fig. 6. Map of slopes.

T a b l e 3. Frequency of slopes.

Class of slope	Area (ha)	Rate (%)
< 15%	3,844.12	37.91
15 % <P< 30%	5,606.47	55.29
30 % <P< 60%	687.50	6.78
> 60%	2.03	0.02
Total	**10,140.12**	**100**

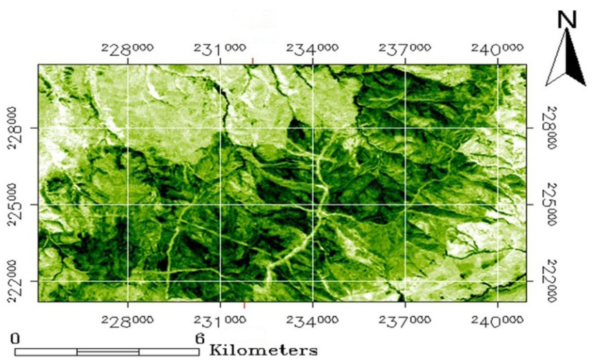

Fig. 7. Map of the NDVI.

The threshold selected, for each class, takes into account the possibilities of executions of forest work (Dagorne, Duche, 1994). The map of slopes obtained is represented by Fig. 6. The classes of average and steep slopes are most dominant with more than 62%. The different percentages of the four classes are summarized in Table 3.

Map of vegetation index (NDVI)

As per the requirements of the study, a vegetation index was calculated from a combination of red tape and near-infra-red in the image Landsat ETM+. This index is used to discriminate the two components of ecosystem: soil and plants on one hand and to calculate the biovolume of the forest on other hand. The formula used to calculate NDVI is given by following equation:

$$NDVI = PIR - (R / PIR) + R \quad (4)$$

where: PIR is the band near-infra-red and R is the red band. The card that is extracted by the application of the vegetation index (NDVI) is represented in Fig. 7.

Map of occupation of ground

The map of occupation of the forest floor of Guetarnia is dominated by the formations of *Pinus halepensis* at 40.91%, *Tetraclinis articulate* at 26.73% and *Quercus rotundifolia* at a rate of 22.34%, and finally, to bare soil and agricultural enclaves in the order of 10.02%. This map highlights the clear dominance of coniferous formations, which were close to 67.64% of the area of the forest and increase the risk of triggering the fires, we have presented in the form of Table 4 and Fig. 8.

T a b l e 4. The distribution of species.

Meaning	Area (ha)	Rate (%)
Pinus halepensis	4, 148.83	40.91
Tetraclinis articulata	2, 710.24	26.73
Quercus rotundifolia	2, 265.36	22.34
Bare Soil	1,015.69	10.02
Total	**10,140.12**	**100**

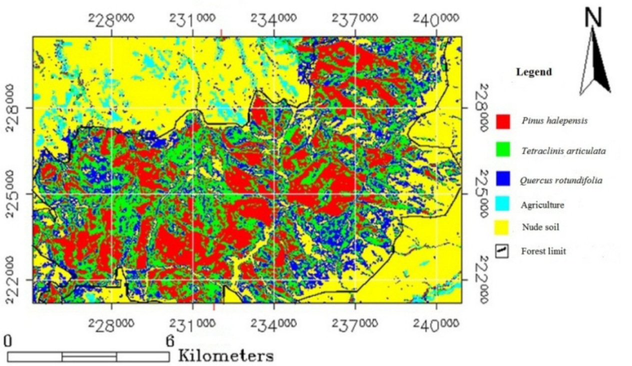

Fig. 8. Map of the occupation of the ground.

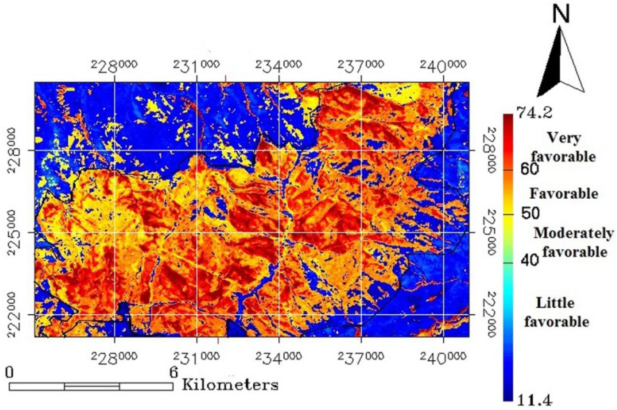

Fig. 9. Map of the index of combustibility.

Exploitation of results

The *risk assessment* is necessary to model each of the elements of risk. The first step is to select the parameters specific to each element (slope, exposure, topomorphology and settlements) and then to use the mode of representation of the risk in order to evaluate. The parameters are the factors of the natural environment and anthropogenic that influences the outbreak, the spread and the intensity of fire, as well as its conduct (aspects related to the fight). The second step based on the intersection of thematic layers by application of the formulas cited previously. The human factor is characterized by the occupation of space, since the forest is not inhabited and is located for enough away from the houses; the human index is equal to zero.

Evaluation of the index of combustibility

The map of index of combustibility, as shown in Fig. 9, has been achieved from the crossing junction of vegetation index layer and occupation layer of the soil. The biovolume was

T a b l e 5. Notes of caloric species (CEMAGREF, 1989).

Tree Species	Note calorific value	Shrubby Species Or herbaceous species	Note calorific value
Pinus halepensis	8	*Rosmarinus*	5
Tetraclinis articulata	7	*Phyllerea*	5
Quercus rotundifolia	7		
Bare Soil	--	--	--

T a b l e 6. Indices of combustibility.

Class	Area (ha)	Rate (%)
IC < 40	1,819.33	17.94
40 < IC < 50	1,234.88	12.18
50 < IC < 60	6,632.63	65.41
IC > 60	453.28	4.47
Total	**10,140.12**	**100**

calculated from the layer of vegetation index, but against the notes of calorie intensity (E_1 and E_2) that have been extracted from the layer of occupation of the ground (Table 5). The two notes caloric of species present in the Guetarnia forest are those established by (Dagorne, and Castec, (1992) ; and Colin et al., (2001) with the exception of *Tetraclinis articulate*, which has been equated with the closest species *Juniperus* (CEMAGREF, 1989).

The values of index of combustibility, took into consideration, four classes ranging from a low rating, medium, high and very high (Table 6).

More than 70% of the surface area of the forest of Guetarnia is located in 'hight' and 'very hight' classes of index of combustibility; the rest is between 'low' and 'medium' severity with values respectively 17.94 and 12.18%. This index typically represents bare soils and areas of low vegetation density (Fig. 9).

Evaluation of the topomorphologic index

The topomorphologic index is obtained by a combination of three criteria (slope, exposure and topomorphology), using the following formula:

$$IM = 3p + e.m \qquad (5)$$

where: p is slope (coded between 1 and 4), ÷*e*÷ is exposure (coded 0 to 3), and *m*÷ represents the morphology of the area (coded of 1 to 4).

This index is a factor in the calculation of risk index, depending on the topographic situation and of the exhibition encountered, aggravating more or less the spread and power of the fire. The results obtained allow us to get four classes of topomorphologic, summarized according to their importance in the Table 7.

Nearly 52% of the surface area of the forest of Guetarnia is located in the conditions topomorphologic little favourable to fire accentuation. The conditions moderately favourable to fire risk cover the surface area of 44.63%, and only 4% is in the range very favourable (Fig. 10).

The topomorphologic index moderately favourable to very favourable represents fractions of high slopes and steep. The slope influences the spread of fire; it accelerates its speed in the catchment area and then, it slows down (Traubaud, 1979; Missoumi, Tadjraoui, 2003).

Evaluation of fire risk index

The evaluation of fire risk index is the result of intersection between the layer of combustibility index and the layer of topomorphologic index. The index is given by the following formula:

$$IR = 5.IC + IM \quad (6)$$

where: *IR* is the Risk index, *IC* is the index of combustibility and *IM* is the topomorphological index.

The forest of Guetarnia is located in medium to strong risk index, covering an area of 8, 189.17 ha or 80.76%. The low risk remains fairly high with a rate of 18.48%; and the resth is barely 1%, is very great danger as the confirmed by the rates as shown in the Table 8 and Fig. 11.

Discussion

The forest of Guetarnia, share its floristic composition diversified, a vegetation density

T a b l e 7. The classes of the index topomorphologic.

Classes	Area (ha)	Percentage (%)
M < 9 (**little favourable**)	5,253.53	51.81
9 < IM < 14 (**moderately favourable**)	2,586.40	25.50
14 < IM < 19 (**favourable**)	1,939.46	19.13
IM > 19 (**very favourable**)	360.73	3.56
Total	**10,140.12**	**100**

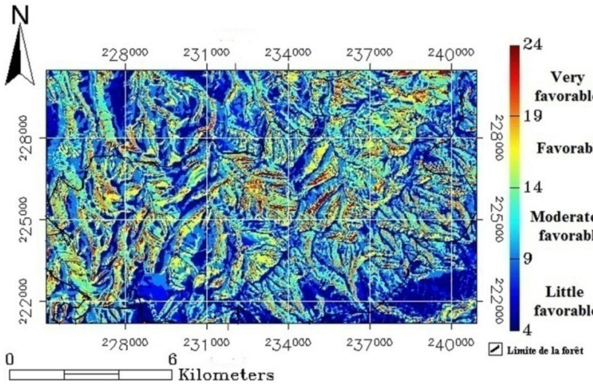

Fig.10. Map of the indextopomorphologic.

T a b l e 8. Indices of fire risk.

Class	Area (ha)	Percentage (%)
IM < 18(**low risk**)	1,873.52	18.48
18 < IM < 27(**medium risk**)	5,748.61	56.69
27 < IM < 36(**high risk**)	2,440.56	24.07
IM > 36(**risk very hard**)	77,44	0.76
Total	**10.140,12**	**100**

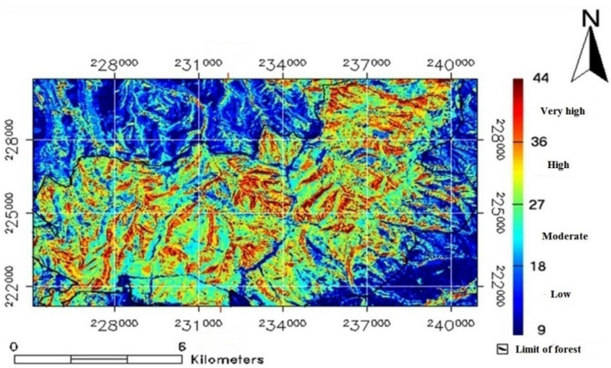

Fig. 11. Map of the index of fire risk.

strong enough and a presence of woody species including the combustibility and flammability are very high is classified in terms of vulnerability to fire risk between medium and high.

The composition and structure of forest stands, in this case the vertical and horizontal distribution of species, determine their flammability and combustibility, and conditioning the process of putting to fire and the power with which the fire is going to maintain and spread (Colin et al., 2001).

Some plant species are more vulnerable to fire than others. The significant presence of the *Pinus halepensis* Mill; the species qualified as being the most flammable and combustible of Mediterranean forests (Velez, 1994; Ramade, 1997; Dimitrakopoulos, Mitsopoulos, 2006); in space and in density determines the high risk of fire of the drill bit.

The matorral is more willing to be damaged by the lights as the forest formations are wooded. This situation is explained quite easily by the difference in the composition of these formations and by the climatic conditions to which they are subjected to. The predisposition of the plant formations to fire is, in effect, related to a large extent to their water content. The latter is strongly influenced by the general conditions of drought (temperature and dryness of the air, lack of precipitation, and episodes of winds dry and violent). These conditions of predisposition are not constant in time. They evolve, for example, according to the state of vegetation, which is the result of both its natural dynamics; forestry is applied to it and of the potential passages of the fire (Assali et al., 2016).

In addition, conditions such as topomorphologic, slope and exposure, which determine the factors that are conducive to triggers and enhance the forest fires. From the point of view of biophysics, the expression of fire in a natural space is a function of its environment, including, of course, climate, the nature of the terrain and the fuel present in the area concerned (Pyne et al., 1996). Therefore, the spatial models that simulate the behaviour of fire, often use as input data the variables measured as altitude, slope, exposure, weather and vegetation (Anderson, 1982; Andrews et al., 2005). These factors are at the origin of the outbreak of the fire and its rapid spread. For example, the angle of slope affects the moisture and conservation of the soil, which in turn affects the distribution of vegetation and its composition, and as a result, the characteristics of the fuel and its flammability (Franklin, 1998).

In effect, the biophysical factors that influence the outbreak of fire and its spread can produce multiple consequences, direct and indirect, on the regime of fire (Whelan, 1995)

This index of risk of lights high enough for the forest of Guetarnia is also the result of almost total lack of silvicultural work and planning. The forest is currently composed of young stands following the escalation of lights on one hand and to high frequency and very close to the lights.

Conclusion

Despite the importance of the phenomenon of forest fires in Algeria, the causes of these fires are still unknown, which complicates any prevention plan. The analysis of information relating to forest fires has revealed that more than 90% of the causes are listed as unknown. The strategy for the management of risk of forest fires in Algeria is support on the intervention where as the techniques having done their evidence are based mostly on forecasts and prevention. However, the forest fires cannot be minimized through prevention, which rests on risk assessment. The map of vulnerability of the forest fires extracted from the forest of Guetarnia shows a model of application of remote sensing and GIS that can be generalized on the forest ecosystems closely, enough. Moreover, the risk map carried out allows demonstratingthe severity of risk incurred following the outbreak of fires from the physical factors (topomorphology, slope and exposure) and biological (vegetation).Thus, it allows to orient the managers in the field of forest fire fighting and to locate the means of intervention for rapid action in time and space.

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