Methodology: Seabirds to Oil Spills

Subjects: Ecology

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Oil spills can have a serious negative effect on seabirds. Numerous studies have been carried out for relative vulnerability assessment of seabirds to oil, with the majority of such works based on ordinal quantities.

Keywords: seabird vulnerability to oil ; measurement scales

1. Introduction

To protect the marine environment, it is extremely important to assess the possible impact of various anthropogenic factors on the marine biota, and oil spills are perhaps the most important aspect here. Various scientific journals offer numerous publications on the issue; the vital components are the development of vulnerability maps for coastal areas for environmental purposes, oil spill response (OSR) plans, and OSR operations [1][2][3][4], as well as vulnerability maps for other liquid chemicals [5][6]. In this study, we consider the vulnerability of marine avifauna (which is an important and one of the most vulnerable components of the marine ecosystem) to oil spills.

In addition to oil, wind farms can have a serious impact on marine biota, because their construction on the shelf may become the most extensive marine engineering project in Europe. Such projects have raised widespread discussion in connection with possible harmful impacts on the environment and, in particular, on seabirds. There are various publications on this issue, as well as on the effect of oil on avifauna [7][8][9][10][11][12], and the approaches to assessing the impact of oil and wind farms on avifauna are largely similar. In [13], the methodology for calculating vulnerability from wind farms was applied with some inevitable changes to assess the impact of oil spills on birds.

When calculating the estimates of the impact of oil spills or offshore wind turbines on avifauna, various specialists often use both values measured on metric (quantitative) scales and those measured on other scales, including ordinal (rank) quantities. When constructing vulnerability maps of coastal-marine zones (taking into account the impact of oil on the avifauna), ordinal quantities (ranks, scores) are used in numerous works [14][15][16][17][18]. Publications devoted to the effect of wind farms on birds, have followed a similar rank-based approach [19]. The key questions here are whether ordinal quantities are admissible in such calculations, and whether the results and conclusions are fully reliable.

Any calculations should take into account the scale on which the initial data were obtained, and whether it is possible to use this data to calculate the impact according to the accepted mathematical models (formulas). However, it is not always possible to use strictly quantitative measurements of individual parameters in order to perform the necessary observations of the environmental consequences of anthropogenic impacts or, in general, in order to assess the environmental impact (EIA). Sociology, psychology, and other social sciences face the same problem, since measurements in the generally accepted sense are impossible, and a qualitative approach is often used, i.e., the necessary parameters are estimated on conditionally quantitative scales, that is, the initial data are expertly evaluated and ranked. Thereby, measurements are obtained on an ordinal scale, and these values are usually denoted by natural numbers (1, 2, 3, .). Various arithmetic operations are carried out afterwards, i.e., the necessary estimates and statistical criteria are calculated. Nevertheless, whether any operations with data measured on a particular scale are permissible depends on the type of scale, on the calculated values, and on the applied algorithms, taking into account the permissible operations and transformations on the corresponding scale [20][21][22][23][24][25][26][27]. In this study, we are more interested in arithmetic operations with values measured on two types of scales (ordinal and ratio), however, to draw a more complete picture, we also provide a brief description of other types of scales.

In this study, we aim to assess (from the metrological point of view, including taking into account the statements of measurement theory) the methodological approaches used for calculating the vulnerability of seabirds to oil spills, the conclusions obtained, and, very briefly, the corresponding vulnerability maps calculated in some studies, and we aim to formulate possible recommendations for further research.

Briefly, we describe measurement theory on various scales (classification of scales, permissible transformations, operations on them, etc.); more details are provided in Appendices A, B, and C. Earlier we have used basic provisions of this theory to analyze application of ordinal quantities in calculations of vulnerability of biota and sea-coastal zones to oil [28][29][30][31][32]. Briefly, general approaches to operations on different scales have been previously described in [29]. In [30], vulnerability map development of sea-coastal zones to oil were assessed considering only unacceptability of arithmetic operations with ordinal quantities. The method of vulnerability assessment of some biota groups and development of vulnerability maps to oil based on metric approach are given in [31][32]. Now, we focus, based on the provisions of measurement theory, on the assessment of earlier studies of birds' vulnerability to oil [33][34][35][36][37], and briefly assess the development of vulnerability maps. These publications [33][34][35][36][37] were chosen since they are frequently referred to in various summarizing works. Additionally, for the aims of our work, it was also important to select publications which provided the initial data in detail (this allowed replicated calculations) and to assess the corresponding approaches to avifauna vulnerability for the development of oil vulnerability maps. While the main focus of our article is the actual calculations with ordinal values, we briefly explore how the application of resultant vulnerability scores could lead to erroneous applications in oil vulnerability mapping.

It becomes clear that in calculations of biota vulnerability to oil (as in any other calculations) it is necessary to use metric values instead ordinal quantities. Furthermore, there is also a need to develop alternative approaches such as the use of ordinal quantities on the ratio scale [38][39]. In this case, it is necessary to take into account the type of data scale, since, even on some metric scales, not all arithmetic operations are permissible. One of the possible options for such an approach for calculating oil vulnerability maps, based strictly on metric values, is described in [32]. All issues raised in our article relate to the calculations of seabirds' vulnerability, which has implications for the development of oil vulnerability maps in any sea region.

2. Arithmetic Operations with Values on Different Scales: Elements of Measurement Theory

2.1. Arithmetic Operations with Values of Various Kinds

In practice, arithmetic operations with certain numbers do not always make sense Their mere relevance to socially relevant applications does not imply that these numbers can always be added and multiplied, or that other arithmetic operations can be performed with them.

The usual arithmetic relations are not always adequate. The opinions of experts are often expressed in an ordinal scale, that is, an expert can say (and justify) that the first influence factor is more dangerous than the second, etc., yet they are not able to say how many times more it is dangerous. Although in arithmetic 1 + 2 = 3, it cannot be argued that, for an object occupying the third place in the ordering, the intensity of the studied characteristic is equal to the sum of the intensities of objects with ranks 1 and 2 (see also Appendices B and C). A rank is a "number" in an ordered series of characteristic values for various objects; in statistics, such series are called variational. Formally, the ranks are expressed by the numbers 1, 2, 3, ., but one cannot perform the usual arithmetic with them.

In addition, it cannot be said that a body with the temperature of 40 °C is twice as warm as one with the temperature of 20 °C, although this is already a strictly quantitative (metric), and not an ordinal scale. Not all arithmetic operations are possible with all the quantities represented by numbers; thus, to analyze this kind of data, we need another theory which provides the basis for the development, study, and application of specific calculation methods, i.e., measurement theory. Initially, it is necessary to take into account the type of scale used to obtain these data.

2.2. Measuring the Quantities: Scales of Measurement

The assessment of anthropogenic impact on birds and the subsequent calculation of vulnerability maps mean, to a certain extent, constructing a reality model based on the results of various measurements (direct measurements, estimates based on observations, and expert estimates). Moreover, the measurement results, as a rule, are obtained on different scales.

In the early 1940s, Harvard psychologist S.S. Stevens introduced the terms nominal scale, ordinal scale, interval scale, and ratio scale to describe the hierarchy of measuring scales used in psychology. In his fundamental work "On the Theory of Scales of Measurement", he presented a hierarchy of data scales based on the invariance of their values for various classes of transformations. Measurement in the broadest sense is the attribution of numerical forms to objects or events in accordance with certain rules, and the fact that numerical forms can be attributed to objects in accordance with different rules leads to the use of different scales and different types of measurements.

Measurement theory is the subject of different publications worldwide, for instance [40][41][42]; these works describe the general theory of measurements on different types of scales in sufficient detail.

Notably, there has been criticism of Stevens's typology of scales. Velleman, Wilkinson [41] wrote that Stevens in his article "Mathematics, Measurement and Psychophysics" went beyond the limits of his elementary typology and classified simple operations, as well as statistical procedures, from the point of view of their "admissibility" for one or another scale. In their opinion, the application of measurement theory "when choosing or for recommending certain methods of statistical analysis is inappropriate and often leads to errors"; a detailed analysis of their arguments and approach is presented in [43]. The discussion on this issue continues, but the typology of the scales as a whole is not questioned and is currently universally recognized. L. Finkelstein, Professor at the University of London, in his opening speech at the congress of the International Measurement Confederation in 1973 called the scale theory "a solid logical basis" for constructing the measurement theory [44]. Classification of scales and permissible operations on them were included in the Russian six-volume Physical Encyclopedia [45], in metrology textbooks, and in various regulatory documents (see below).

The first classification of scales by Stevens does not fundamentally differ from the modern generally accepted classification, although there are several similar classifications. Let us very briefly describe the main measurement scales.

Currently, scales are usually grouped into nominal (for quality measurements); ordinal (to reflect the relationship of order (bigger, better, more important, etc.)); and quantitative (based on the usual arithmetic operations, for example, 10 is two times more than five). Sometimes all the measurement scales are divided into the following two classes: scales of qualitative attributes or non-metric scales (ordinal scale and nominal scale) and scales of quantitative attributes or metric (quantitative) scales.

The definitions of certain basic concepts of measurement theory (value, measurement scale, and measurement) from the International Vocabulary of Metrology are given in Appendix A. The concept of measurement is the most important for the present study, and in [46] 23 different definitions are given (see also [[40][41][42]). One can proceed from the following definition of this concept, which does not contradict the one given in [26], i.e., measurement is the construction of scales by isomorphic mapping of an empirical system with ratios into a numerical system with ratios. Formally, a scale is a triple that consists of a set of x_i elements, a binary operation "O" on x_i elements, and a transformation of φ (for x_i) into real numbers.

2.3. Methods for Obtaining Measurement Information

Obtaining measurement information is possible in one way, i.e., by comparing the properties (values) of the measured objects. Leonhard Euler, renowned Swiss, German, and Russian mathematician and mechanic, wrote: "It is impossible to determine or measure one value otherwise than by accepting another value of the same kind as a known and indicating the relation between them." All the cases of comparison of two values of Q_1 and Q_2 are reduced to three options [47]:

$$Q_i > Q_j,\ Q_i < Q_j, \tag{1}$$

$$Q_i - Q_j = \Delta Q_{ij} = q_{ij}[Q], \tag{2}$$

$$Q_i/Q_j = q_{ij}. \tag{3}$$

The first option, Option (1), is the simplest and least informative. An experimental solution to the inequality answers the question of which of the two is larger than the other, however, it does not state how much exactly one is larger than the other, or how many times. A more informative comparison is Option (2), since it does answer the question "how much", however, it is still impossible to answer "how many times", as in Option (1). To answer this question, Option (3) is needed, since it can determine how many times Size Q_j fits into Size Q_i. This means that Q_j acts as a unit of measure, and certain requirements are imposed on units of measure. Thus, Option (3) is the most informative.

2.4. Types of Measurement Scales and Their Main Characteristics

The scale is best represented in terms of a class of transformations that preserve the information contained in it . The type of scale defines a class of permissible transformations of the scale that do not change the objectively existing ratios between measured objects. The opposite is also true, i.e., permissible transformations determine the type of scale. Let us give the classification, features and characteristics of the main types of scales that currently exist, using the data from several publications [46]. Appendix B provides additional information on the subject.

Nominal scales reflect quality properties. Their elements are characterized only by the relations of equivalence (equality), differences, and similarities of specific qualitative manifestations of properties. All mutually unique transformations are admissible on them. These scales do not allow introducing the concepts of the unit of measurement, and therefore of dimension, and they lack the zero element. However, some statistical operations are possible when processing the measurement results in these scales, for example, one can find the modality class, or the most numerous equivalence class, based on the measurement results.

Ordinal scales describe properties for which the equivalence and also the relations in increasing or decreasing of the quantitative manifestation of the property are meaningful in accordance with Option (1) of comparing the values. These scales also do not allow introducing units of measurement, since they are fundamentally nonlinear, i.e., it is logically impossible to establish the equality of intervals in different parts of the scale. The measurement results in such scales are expressed in numbers, scores, degrees, levels, and not in units of measurements. Although the results of measurements on such scales are often indicated by continuous sets of real arithmetic numbers, it is impossible to imply the proportionality of these values (it is logically impossible to determine how many times one implementation of a property is more or less than another). Measurement results in scores, degrees, and levels are often expressed by discrete rows of natural numbers. Ordinal scales allow monotonic transformations; zero of the scale can be present in them.

In the international dictionary of metrology, the definition of ordinal quantity is stated as followed: "Quantity, defined by a conventional measurement procedure, for which a total ordering relation can be established, according to magnitude, with other quantities of the same kind, but for which no algebraic operations among those quantities exist. Ordinal quantities can enter into empirical relations only and do not have measurement units or quantity dimensions. Differences and ratios of ordinal quantities have no physical meaning (item 1.26) (full definition is given in Appendix A).

Difference scales (interval scales*)* differ from ordinal scales, i.e., for the properties they describe the equivalence and order relations make sense, as well as the equality and summation of the intervals (differences) between different quantitative manifestations of the properties. Interval scales with size Q are described by the following equation:

$$Q_i = Q_j + q_{ij}\,[Q], \tag{4}$$

where Q_i is the value of the physical quantity, Q_j is the origin, q_{ij} is the numerical value of the interval of the physical quantity, and $[Q]$ is the unit of measurement of the physical quantity in question. As follows from Option (4), the interval scale is completely determined by setting the origin Q_j and unit of measurement $[Q]$.

A typical example here is the scale of time intervals. Time intervals (for example, work periods or study periods) can be added and subtracted, but it is pointless to add up the dates of any events. Scales of this type also include practical temperature scales with a conditional zero (Celsius, Fahrenheit, Réaumur). Interval scales have conditional (accepted by agreement) units of measure and conditional zeros based on any benchmarks; in these scales, linear transformations are permissible.

Equivalence and order relations, as well as subtraction and multiplication operations (for ratio scales of the first and second type, see Appendix B) are applicable to the set of quantitative manifestations in ratio scales. From a formal point of view, ratio scales are interval scales with a natural origin, and are the most advanced measuring scales. Their equation is as follows:

$$Q = q[Q], \tag{5}$$

where Q is the value of the physical quantity, q is the numerical value of the physical quantity, $[Q]$ is the unit of measurement of the physical quantity. Ratio scales have no natural unit of measure, yet they have conditional (accepted by agreement) units and natural zeros. These scales are widely used in physics and technology; all the arithmetic operations are allowed in them, except for summation in scales of the first type.

Permissible transformations, here, are similar transformations (changing only the scale), in other words, linear increasing transformations without a constant term. In the ratio scale values of one scale can be converted to another scale of values by multiplication by a positive constant (for example, kilometers into nautical miles by multiplying by a factor of 1.852, or $y = a \times x$). Moreover, the ratio of two ordered observations is preserved, however, in an interval scale it changes with an allowable transformation (the Celsius scale has one ratio of two intervals, the Fahrenheit scale has another, although these are differences of two identical temperature states of matter); for more details, see Section Appendix B3 of Appendix B.

Absolute scales have all the attributes of a relation and have a natural unambiguous definition of a unit of measure. Such scales are used to measure the following relative values (the relation of the same values): bird numbers, amplification, attenuation, reflection, and absorption coefficients, etc.

Thus, (taking into account the provisions of the modern measurement theory) it can be argued that it is not permissible to perform any arithmetic operations with all types of data, even on metric scales. Emphasizing again that no algebraic operations among ordinal quantities exist and differences and ratios of ordinal quantities have no physical meaning. Not all actions are permissible and on differences and intervals scales. In mathematical modeling of a real phenomenon or process, it is necessary to establish on which type of scale certain variables are measured. The type of scale defines a group of permissible scale transformations. The opposite is also true, i.e., the group of permissible transformations determines the type of scale.

3. Conclusions obtained from the analysis of publications where seabirds vulnerability to oil are assessed, and where calculations are based on arithmetic operations with ordinal quantities.

Summation of ordinal quantities in calculating vulnerability of seabirds sometimes leads to ambiguous correlations between the results and, accordingly, to ambiguous conclusions. The ratio of the final calculated estimates of the vulnerability indices and obtained vulnerability maps becomes dependent on the choice of certain ordinal quantities when these selected values are connected by permissible transformations on the ordinal scale. That is, individual conclusions (for instance, which indices for species of birds or their families are larger/smaller, or how many times they are larger/smaller with permissible scale transformations) often change with such permissible transformations. The conclusions based on values (*OVI, BOI, IV, PV)* which include arithmetic means of ordinal quantities are not invariant to permissible transformations.

Multiplication of ordinal quantities leads to the change in the order of the final results (products), as if one could proceed from the metric (but unknown) values of the initial parameters. In fact, the multiplication of ordinal quantities leads to partially uncertain results. Moreover, the researcher does not even know which results are incorrect. Values (*BOI, IV, PV,* V_x) calculated using ordinal quantities have hidden uncertainties.

The transition from the known initial metric values to ordinal quantities, i.e. replacing the former with the latter distorts real relations between the initial data, which significantly affects the final result of the calculation of the vulnerability indices and vulnerability maps of seabirds (calculation of *BOI*). Calculations with ordinal quantities in a limited range of variability (for example, 0-3 or 0-5), most likely, also do not correspond to the real relations of appropriate metric values and lead to incorrect results (calculations of *OVI, BOI, IV, PV,* V_x, and others).

The most important about arithmetic calculations with ordinal quantities is that ordinal quantity is "quantity, defined by a conventional measurement procedure, for which a total ordering relation can be established, according to magnitude, with other quantities of the same kind, but for which no algebraic operations among those quantities exist. Ordinal quantities can enter into empirical relations only and do not have measurement units or quantity dimensions. Differences and ratios of ordinal quantities have no physical meaning"(item 1.26).

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