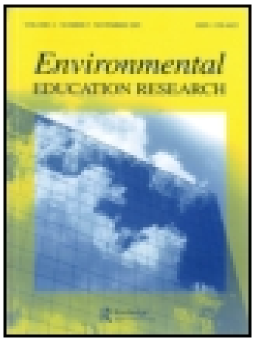

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Measuring ocean literacy in pre-service teachers: psychometric properties of the Greek version of the Survey of Ocean Literacy and Experience (SOLE)

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The aim of the present study was to respond to the increasing demand for comprehensive tools for the measurement of ocean literacy, by investigating the psychometric characteristics of a Greek version of the Survey of Ocean Literacy and Experience (SOLE), an instrument that assesses conceptual understanding of general ocean sciences content, focusing on the knowledge component. Four hundred twenty-one pre-service primary school teachers participated in a cross-sectional study. The dichotomous Rasch model was used to examine the measurement properties of the SOLE, namely, person-item targeting and separation, reliability, dimensionality and differential item functioning (DIF). Steps were taken to improve the instrument, where any of these attributes were outside acceptable ranges. Results suggested that a modified SOLE showed an adequate fit to the Rasch model, is unidimensional, free of DIF, and is particularly well-suited to the population under study. Our findings suggest that the SOLE constitutes a valuable tool which can be applied to a different cultural context and population. The proposed use of the instrument could contribute to the assessment of the quality of marine education in school-based and non-formal education contexts and to the cross-cultural comparison of ocean literacy, which are prerequisites for the improvement of ocean literacy.

Keywords: ocean literacy; SOLE; Rasch analysis

Introduction

An individual's environmental literacy is the outcome of a number of interplaying attributes: affect, ecological knowledge, socio-economic knowledge, knowledge of environmental issues, skills, additional determinants of environmentally responsible behavior, and environmentally responsible behavior (Simmons 2001). Given that the ocean is the dominant feature of the planet and the 'conceptual glue' that binds together much of the Earth science systems content (Hoffman and Barstow 2007), one cannot be science or environmentally literate without being literate in ocean and aquatic concepts (Payne and Zimmerman 2010). Therefore, understanding the ocean is essential to understanding and, thereby, protecting the planet on which we live (Cava et al. 2005). The necessity of marine and aquatic education had been underlined and studied in 1970s onwards (Charlier and Charlier 1971; McFadden 1973;

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Picker 1980; Fortner and Lyon 1985). However, ocean and aquatic concepts are infrequently taught and rarely appear in K-12 curriculum materials, textbooks, assessments, or standards (e.g. see Hoffman and Barstow [2007]). Additionally, educational research has paid little attention to teaching and learning ocean and aquatic science concepts in contrast to other areas of science such as chemistry, physics, and biology (Payne and Zimmerman 2010).

The need for communication and a way to build community consensus on ocean literacy was firstly addressed in 2004 (Cava et al. 2005). After an extensive process of continuous meetings and constructive discussions, ocean literacy was defined as 'the understanding of the ocean's influence on you and your influence on the ocean' and its essential principles were identified. These principles, which are included in the Ocean Literacy Brochure (NOAA 2013), are the following:

(1) The Earth has one big ocean with many features.
(2) The ocean and life in the ocean shape the features of Earth.
(3) The ocean is a major influence on weather and climate.
(4) The ocean made Earth habitable.
(5) The ocean supports a great diversity of life and ecosystems.
(6) The ocean and humans are inextricably interconnected.
(7) The ocean is largely unexplored.

Each of the principles is underpinned by a series of fundamental concepts, 45 in total (NOAA 2013), which support and explain the principles. The development of ocean literacy principles is in line with the development of conservation literacy guidelines by the Society for Conservation Biology (Trombulak et al. 2004) and reflects the wider conceptual framework of conservation biology in the ocean system specifically.

Information regarding the level of ocean literacy around the world is rather sparse. The small body of studies conducted before the ocean literacy movement in 2004, have focused on students and have taken place mostly in the USA (Fortner and Teates 1980; Fortner 1985; Fortner and Mayer 1989; Howick 1991; Brody 1996; Lambert 2005), as well as in other countries such as the UK (Revell, Stanisstreet, and Boyes 1994), Canada (Cummins and Snivelly 2000), South Africa (Ballantyne 2004), and Israel (Ben-Zvi-Assarf and Orion 2005). Among the few studies having been conducted after 2004, the focus has also been on students (Greely 2008; Marrero 2009; Plankis and Marrero 2010; Kim 2014), as well as on the general public in the USA (Steel et al. 2005; Fletcher et al. 2009; Hynes, Norton, and Corless 2014), on high school students in Canada (Guest, Lotze, and Wallace 2015), university students in Taiwan (Chen and Tsai 2015) and pre-service teachers in Greece (Boubonari, Markos, and Kevrekidis 2013). The paucity of relevant studies underline the necessity to measure the level of knowledge of ocean sciences issues in various cultures and target groups. These measurements could allow the assessment of the quality of marine education in school-based and non-formal education contexts and the cross-cultural comparison of ocean content knowledge.

Measurement of an individual's knowledge about ocean sciences issues requires tools which are aligned with the essential principles and the fundamental concepts of ocean literacy and possess well-established psychometric properties. Questionnaires were used as the main research instrument applied to measure ocean sciences content knowledge (Fortner 1985; Cummins and Snivelly 2000; Greely 2008;

Plankis and Marrero 2010; Boubonari, Markos, and Kevrekidis 2013), while interviews were conducted to a lesser extent (Fortner and Lyon 1985; Revell, Stanisstreet, and Boyes 1994; Brody 1996; Ballantyne 2004). However, only few of these questionnaires were subjected to some type of validity and reliability evaluation. Moreover, to our knowledge, the questionnaire developed by Greely (2008) is the only one that drew upon all the essential principles and fundamental concepts of ocean literacy.

Greely (2008) developed a 57-item multiple choice questionnaire, the Survey of Ocean Literacy and Experience (SOLE), to assess secondary students' ocean-related knowledge in the USA. The items were close-ended, which made the instrument easy to use, code and score for statistical analyses. Item distractors, a term used in the literature to indicate plausible but incorrect response options presented with each item, were designed to probe for common student misconceptions. The SOLE was pilot tested among a sample of marine science graduate students and a sample of high school students enrolled in marine science courses. The instrument's construct validity and internal consistency, as well as its ability to effectively distinguish between individuals with different levels of understanding were demonstrated by means of Rasch analysis (Greely 2008). The study findings revealed that the participants' content knowledge contributed significantly to their ocean literacy. However, the data were derived from individuals enrolled in a self-selected summer experiential, outdoor environmental program and, as such, results may not be generalized across populations. Moreover, the instrument was calibrated with relatively small sample sizes (n = 30 and n = 105) and further research is clearly needed to replicate these findings with larger samples and different populations.

The family of Rasch models, based on the original ideas and theory of Rasch (1960), has been widely employed for the psychometric evaluation of assessment instruments in science education (Boone and Scantlebury 2006; Boone, Townsend, and Staver 2011; Boone, Staver, and Yale 2014). The main outcome of a Rasch analysis is a unidimensional line or continuum along which test items and persons are located according to their difficulty and ability measures, respectively. Ability is used here as a generic term to indicate the level of achievement of a person on a particular test in a particular area. The response patterns observed on the test items are examined against the model requirements, which include latent monotonicity, local independence, unidimensionality and specific objectivity (e.g. see Wilson [2004]; Bond and Fox [2007], for an introduction to Rasch analysis). Rasch models are compatible with fundamental measurement (Boone, Townsend, and Staver 2011) and offer certain advantages as construct validation tools (Smith 2001; Baghaei 2008). In particular, the dichotomous Rasch model, is one of the dominant models for analyzing binary items (e.g. success/failure) in psychometrics and assumes that the probability of a given person endorsing a questionnaire item is a logistic function of the difference between the item location (or item difficulty) and the person location (or person ability) on a linear scale (Bond and Fox 2007).

Considering the increasing demand for standardized tools (see also Hoffman and Barstow 2007; Plankis and Marrero 2010), as well as the lack of comprehensive instruments, adaptation of instruments developed in different countries or target groups is considered an efficient solution for the measurement of ocean literacy. However, since constructs and concepts may convey different meanings in different cultures and in different target groups, an adapted instrument should be regarded as needing further evaluation of its measurement properties. Therefore, considering that

Greely's (2008) questionnaire is the only instrument which drew upon all the principles and concepts of ocean literacy, an important step would be to examine whether this instrument is effective in different cultural settings and in different target groups.

Teachers are a target group of great interest, considering that successful integration of ocean literacy in schools, among others, requires the commitment of teachers who have a good knowledge of ocean literacy principles and concepts (Boubonari, Markos, and Kevrekidis 2013). Teachers' knowledge of the content affects both what they teach and how they teach it, emphasizing those areas in which they are more knowledgeable and avoiding or de-emphasizing the areas in which they have relatively less content knowledge (Grossman 1995). Their knowledge is of great importance particularly in Greece, a country with an extensive length of coastline and numerous islands. The sea plays a key role in the formation of Greek history and culture and provides important economic benefits, such as marine transportation and trade, coastal tourism, commercial fishing, fish culture, as well as a recreational value to boaters, fishermen and beach goers.

The main aim of the present study is to respond to the increasing demand for comprehensive and standardized tools for the measurement of ocean literacy, by investigating the psychometric characteristics of a Greek version of the SOLE in a sample of pre-service primary school teachers, using Rasch analysis. The psychometric investigation of the Greek version of the SOLE could provide evidence for the scale's effectiveness in a different cultural context and target group. Moreover, it could contribute to the assessment of the quality of marine education in different educational contexts and to the cross-cultural comparison of ocean literacy, which are both prerequisites for the improvement of ocean literacy.

Methodology

Participants and procedure

A cross-sectional study was conducted to a sample of pre-service teachers attending the Department of Primary Education at Democritus University of Thrace. In Greece, pre-service teacher education is carried out in four-year university training programs, which prepare either professionals as generalist teachers with no subject specialization, graduating with a bachelor of education degree and a teaching certificate, obtaining the ability to teach in primary schools (grades 1–6), or professionals with a certain subject specialization, graduating with a bachelor of science, mathematics or linguistics and a teaching certificate, obtaining the ability to teach in junior and high schools (grades 7–12), respectively.

Participants were randomly selected from lists of currently enrolled students, with the constraint that individuals fit into groups stratified by year of study and gender. Each student was sent a letter of introduction to the study by e-mail, invited to participate, and asked for a reply within two weeks. Only eight individuals declined to participate and were replaced. Fifteen participants gave incomplete questionnaires and were dropped from the study. As a result, the final sample consisted of 421 pre-service primary school teachers with a mean (± standard deviation) age of 20.33 ± 0.96 years. Approximately 19% of the sample were students in their first year of study (n = 78), 26% in their second year (n = 110), 30% in their third year (n = 126) and 25% in their fourth year (n = 107). Females constituted 86.7% of the participants (n = 365). This proportion reflects the average gender distribution of pre-service primary teacher population in Greek education departments, while this bias seems to be common across the globe (Watson and Halse 2005).

Measures

The SOLE questionnaire (Greely 2008) contains a total of 57 general ocean sciences content questions and is the main instrument used in this study. Each correct response receives a numeric value of 1 and incorrect responses are coded 0. Table 1 contains a summary of the number of questions asked and their alignment with the seven essential principles of ocean literacy. The Greek version of the SOLE was developed using forward and backward translation by a marine biology professor and a marine educator with solid command of the English language. Differences in translation were resolved through consensus.

The original 57 SOLE items (Greely 2008) were reviewed for clarity, accuracy, and the extent to which they represent the associated ocean literacy essential principles. An English translation of the revised Greek version of the SOLE is presented in Appendix 1. The revised Greek version contains 54 items. As a result of the revision process, two items were eliminated as United States-specific (former items 12 'Many earth materials originated in the ocean. Which rock type now exposed on land in the Southwest US formed in the ocean?' and 24 'What is the source of most trash on the beaches in the US?'), and one as ambiguous (former item 57 'Which of the following statements is most relevant to ocean literacy? Much of the world's population lives … (a) near rivers, (b) in rural areas, (c) in coastal areas, (d) in mountain areas, (e) in wooden areas'). For the latter item, the meaning of the question is not clearly related to the sentence that follows and the meaning of 'much' was considered ambiguous regarding the options provided.

Furthermore, proper adaptation of the questionnaire to the experience of Greek students, as well as issues of item clarity, mandated slight modification of eleven items. Thus, item 9 of the original instrument, having too many response options which were deemed potentially confusing, was modified as follows: 'What approximately is the maximum depth of the ocean? (a) 11 km (b) 6 km (c) 2.8 km (d) 17 km (e) 22 km'. The questions in items 36 (former item 38) and 43 (former item 45) were rephrased according to the ocean literacy brochure ('major groups of organisms' replaced 'organisms' in item 36 and 'influencing' replaced 'that influence' in item 43). In the case of items 7, 13, 23 and 30 (former items 7, 14, 25, 32),

Table 1. Groups of SOLE questions in alignment with the seven Essential Principles of ocean sciences.

Essential principle	No. of questions	Instrument
1. Size of ocean	15	SOLE (1–14, 19)
2. Ocean & its life shape Earth	6	SOLE (15–17, 20–21, 24)
3. Weather & climate	9	SOLE (18, 23, 26–32)
4. Habitability	1	SOLE (37)
5. Biodiversity	13	SOLE (33–36, 38–46)
6. Human connections	6	SOLE (22, 25, 50, 52–54)
7. Oceans largely unexplored	4	SOLE (47–49, 51)
Total	54	

response options (percentages) being very close to the correct percentage were deleted as potentially confusing. With regard to item 20 (former item 21), the response option about 'gopher tortoises' was deleted since this is a species of the *Gopherus* genus native to the southeastern United States. According to Clark (2001, 65, Table 4.1, 72), who was based on estimates from the UN Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) and reports that most oil in the sea comes from atmospheric emissions by evaporation of petroleum hydrocarbons from the cargoes of oil tankers, item 22 (former item 23) was corrected by substituting the 'used motor oils washed into storm drains' response option with 'evaporation from oil cargoes which returns to ocean by rain out'. In item 40 (former item 42), response options 'phyto-plankton' and 'zoo-plankton' were considered inaccurate and misleading. Traditional concepts of 'plant' and 'animal' are unsatisfactory, while the term phytoplankton now refers to all photosynthetic microbes; moreover, a part of zooplankton is also included in the microbes (Munn 2011). Consequently, there is an overlap between these two terms and microbes. Therefore, they were replaced by 'seaweeds' and 'marine mammals'. Finally, for item 50 (former item 52), the response option which concerned national security was deleted as ethnocentric.

Data analysis

Student responses in the revised SOLE were evaluated using the dichotomous Rasch model, in order to obtain a measure that reflects an individual's overall knowledge of the ocean. Rasch analysis was implemented with Winsteps v3.71 software (Linacre 2011) and involved the following steps.

Dimensionality

The unidimensionality requirement of the Rasch model was assessed through Principal Component Analysis (PCA) and evaluation of item fit statistics. A PCA of the standardized residuals was calculated after controlling for the Rasch dimension. According to Linacre (2011), fundamental unidimensionality is achieved when the variance explained by the model is greater than 50% and if the eigenvalue of the first component of residuals is small (usually less than 2.0). A less-stringent criterion proposed by Reckase (1979), suggests that the percentage of variance explained should be greater than 20% and that there should not be a second dominant factor (the eigenvalue of the first component of residuals less than 3.0). The standardized residual correlations were also examined to identify locally dependent items. Local independence of items requires that the probability of getting one item correct is independent of the probability of getting another item correct (Linacre 2011). Items with residuals that highly correlate (>0.05) were reviewed as to whether they duplicate each other.

Item fit statistics indicate how well each item contributes to the measurement of a single underlying construct and include the Infit and Outfit mean square standardized errors and their *t*-transformed statistics. Infit and Outfit have an expected value of 1.0. Infit or Outfit values greater than 2.0 suggest serious distortion or degradation of measurement, whereas misfit is considered to be moderately high if these statistics range between 1.5 and 2.0 (Linacre 2002). Point-measure (or point-biserial) correlations were also examined, as a measure of how strongly each item is measuring the direction of the construct.

Reliability

The internal consistency of the SOLE was assessed using item and person reliability and separation indices. Person reliability indicates the replicability of person ordering expected if the sample were given another set of items measuring the same construct, whereas item reliability specifies the replicability of item placements along the scale if these same items were given to another same-sized sample with similar knowledge levels (Bond and Fox 2007). Values above 0.8 for persons and items are generally considered satisfactory (Linacre 2011). Separation refers to the number of statistically different performance strata that the test can identify in the sample (Wright 1996). A person separation index above 2.0 implies that the instrument is sensitive enough to distinguish between high and low performers and an item separation index above 3.0 implies that the person sample is large enough to confirm the item difficulty hierarchy (construct validity) of the instrument (Linacre 2011).

Targeting

Targeting refers to the extent to which items target the abilities of the examinees and was assessed through the plotting of item calibrations along a linear scale in logits. The logit is the natural logarithm of the odds of a person being successful at a specific item (person ability) or an item being successfully carried out (item difficulty). Conventionally, 0 logit is ascribed to average item difficulty. For instance, a person with a measure of 0 logits on the scale, has about a 50–50 chance of success on the items of average difficulty, a greater chance of success on the easier items (those with calibrations lower than 0), and a lesser chance of success on the more difficult items (those with calibrations higher than 0). An instrument that is well-targeted to the intended sample will show that the cluster of persons is located opposite to the cluster of items (Bond and Fox 2007). The hierarchical ordering of items along the scale is compared to that which was predicted prior to data analysis. In addition, the functioning of distractors, i.e. plausible but incorrect response options presented with each item, was evaluated. From a Rasch perspective, a multiple-choice item is functioning well when students who have chosen the correct option have a higher average ability than the students who have chosen any of the distractors (Bond and Fox 2007). Effective distractors should discern a wide range of student ability and attract lower ability students, those with misconceptions or limited knowledge.

Differential item functioning

Rasch analysis also facilitates the assessment of differential item functioning (DIF). DIF occurs when persons from different groups (e.g. gender or ethnicity) with the same underlying ability have a different probability of responding to an item in a particular way. Assessment of DIF is important as it improves generalizability of the instrument by testing that items function similarly for all persons of the same ability. To ensure that characteristics other than item difficulty do not bias the functioning of the SOLE measure, DIF was assessed for gender (male/female) with a Bonferroni adjusted alpha level (critical value of 0.001) and a difference in item locations (DIF contrast) of 0.5.

Results

Dimensionality

The results of PCA of the standardized residuals indicated that the first component explained 42.3% of the total variance with an eigenvalue of 2.67 < 3, which represents a residual variance of 4.8% and is just below the value of 5%. These provide evidence that the standardized residuals have no additional systematic information and suggest the unidimensionality of the revised SOLE scale. With regard to local independence, the largest standardized residual correlations for the items in the SOLE were between −0.17 and 0.40, which indicates that no pairs of items shared half or more of their random variance. Consequently, there was no evidence of sizeable local dependence.

Table 2 reports item fit statistics in addition to percentage correct scores. These include item difficulty estimates, infit and outfit mean square standardized errors and point-measure correlations. Item fit statistics were within acceptable range, except for two items. Item 8 'The ocean is connected to all the earth's water reserves (supplies) via …' and Item 9 'What approximately is the maximum depth of the ocean?' had large outfit values (1.73 and 1.51, respectively), indicating unexpected response patterns. Closer examination revealed that the two items were among the most difficult for our sample and received unexpectedly correct answers by a small number of less able respondents. These items are considered unproductive for measurement construction but not degrading to the overall analysis, and were thus retained. All items had positive point-measure correlations that ranged from 0.16 to 0.53, suggesting that these items contribute information to the construct measured by the test as a whole.

Reliability

The SOLE showed satisfactory internal consistency. Item reliability was 0.99 and item separation was 9.52, which implied a broad continuum of measurement. Person reliability was found to be 0.86 and person separation was 2.44, indicating that the 54 items could reliably distinguish at least three ability levels of the participants in our sample. The average standard errors of persons (0.17 logits) and items (0.13 logits) were low.

Targeting

For the data in the present study, the item measures ranged from –2.37 to 2.46 logits, while pre-service teachers ranged in ability to report ocean science issues from −3.85 to 2.23 (Figure 1 and Table 2). The mean difficulty of the items (0.00) was only marginally greater than the mean reporting knowledge of the individuals (−0.17), suggesting that the items were somewhat difficult for the pre-service teachers to endorse. The overlap between the range of the person trait levels and that of item difficulty levels indicates that the 54 items are adequate to assess pre-service

Table 2. SOLE item estimates (n = 421).

Item	%	Cor	Difficulty (logits)	Error (logits)	Infit	Outfit	Item	%	Cor	Difficutly (logits)	Error (logits)	Infit	Outfit
1	79.1	0.21	−2.07	0.13	1.23	1.33	28	28.5	0.32	0.56	0.11	0.99	1.03
2	43.5	0.25	−0.19	0.11	1.12	1.19	29	17.3	0.21	1.28	0.13	1.05	1.16
3	45.4	0.35	−0.28	0.11	1.01	1.05	30	7.1	0.34	2.35	0.19	1.02	1.22
4	62.5	0.42	−1.10	0.11	0.97	0.94	31	58.2	0.48	−0.89	0.11	0.91	0.88
5	26.1	0.28	0.70	0.12	1.03	1.05	32	30.9	0.35	0.43	0.11	0.99	0.96
6	55.1	0.43	−0.74	0.11	0.94	0.96	33	41.6	0.21	−0.10	0.11	1.15	1.17
7	6.3	0.24	2.46	0.21	0.96	0.92	34	59.4	0.36	−0.95	0.11	1.02	1.03
8	11.9	0.16	1.76	0.16	1.02	1.73	35	76.0	0.52	−1.86	0.12	0.85	0.79
9	12.1	0.17	1.73	0.15	1.06	1.51	36	40.1	0.21	−0.03	0.11	1.12	1.30
10	31.3	0.34	0.41	0.11	0.98	1.04	37	35.6	0.25	0.19	0.11	1.10	1.09
11	43.2	0.40	−0.18	0.11	0.95	1.01	38	22.3	0.26	0.93	0.12	1.02	1.10
12	29.4	0.31	0.51	0.11	1.02	0.98	39	36.8	0.31	0.13	0.11	1.03	1.06
13	18.5	0.23	1.19	0.13	1.03	1.12	40	29.9	0.27	0.48	0.11	1.06	1.05
14	67.2	0.45	−1.35	0.11	0.93	0.92	41	73.2	0.47	−1.68	0.12	0.91	0.88
15	59.4	0.53	−0.95	0.11	0.85	0.82	42	43.5	0.50	−0.19	0.11	0.87	0.82
16	51.8	0.43	−0.58	0.11	0.95	0.96	43	14.9	0.30	1.47	0.14	0.97	0.87
17	42.9	0.38	−0.17	0.11	0.99	0.96	44	29.2	0.42	0.52	0.11	0.91	0.85
18	54.2	0.48	−0.70	0.11	0.91	0.87	45	6.6	0.25	2.43	0.20	0.95	0.72
19	83.1	0.40	−2.37	0.14	0.96	0.89	46	27.8	0.30	0.60	0.12	1.01	1.03
20	58.7	0.50	−0.91	0.11	0.89	0.85	47	13.8	0.21	1.57	0.15	1.02	1.16
21	78.1	0.34	−2.00	0.13	1.01	1.09	48	57.0	0.43	−0.83	0.11	0.95	0.94
22	16.6	0.45	1.33	0.14	1.10	1.20	49	54.6	0.45	−0.72	0.11	0.94	0.90
23	8.8	0.28	2.11	0.18	1.02	1.22	50	65.3	0.52	−1.25	0.11	0.87	0.81
24	56.5	0.37	−0.81	0.11	1.01	1.02	51	25.4	0.29	0.74	0.12	1.00	1.11
25	29.4	0.21	0.51	0.11	1.10	1.20	52	66.2	0.40	−1.30	0.11	0.99	1.00
26	59.9	0.44	−0.97	0.11	0.95	0.91	53	62.0	0.44	−1.08	0.11	0.95	0.93
27	39.9	0.27	−0.02	11	1.08	1.11	54	62.0	0.46	−1.08	0.11	0.93	0.90

Note: % = percentage correct score, Cor = point-measure correlation.

Hardest items ↑ … ↓ Easiest Items	Item	Measures (logits)	Error (logits)	Selected Items
	7	2.46	0.23	Approximately how much of the earth's water is fresh and unfrozen (neither ice nor ocean)?
	45	2.43	0.20	Deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms are…
	30	2.35	0.19	The ocean dominates the earth's carbon cycle. Approximately how much primary production on earth takes place in the sunlit areas of the ocean?
	23	2.11	0.18	The ocean dominates the earth's carbon cycle. Approximately how much of all the carbon dioxide in the atmosphere is absorbed by the ocean?
	8	1.76	0.16	The ocean is connected to all the earth's water reserves (supplies) via…
	9	1.73	0.15	What approximately is the maximum depth of the ocean?
	47	1.57	0.15	The ocean is the last and largest unexplored place on earth. How much of the ocean remains unexplored?
	43	1.47	0.14	Which of the following causes vertical zonation patterns along the shore influencing the distribution and diversity of organisms?
	22	1.33	0.14	Which sources put most oil in the ocean?
	29	1.28	0.13	Global weather is changed by the El Nino Southern oscillation by changing the way heat is released in the atmosphere over which ocean basin?
	54	-1.08	0.11	Which natural hazards can impact coastal regions?
	4	-1.10	0.11	The movement of the earth's lithospheric plates influences an ocean basin's…
	50	-1.25	0.11	Which of the following statements are true about the ocean?
	52	-1.30	0.11	What does the statement, the ocean and humans are inextricably connected mean?
	14	-1.35	0.11	Which of the following are transported by rivers from watersheds to estuaries and to the ocean?
	41	-1.68	0.12	In the ocean living spaces and habitats are found…
	35	-1.86	0.12	What happens to sunlight in the ocean as depth increases?
	21	-2.00	0.13	If our planet were without its ocean but otherwise the same as it is today, would surface temperatures be more extreme than they are now (warmer summers and colder winters) or less extreme, or what?
	1	-2.07	0.13	Approximately how much of the earth is covered by ocean?
	19	-2.37	0.14	Water moves from the ocean to the atmosphere to the land and back again to the ocean by a process called…

Figure 1. Revised Survey of Ocean Literacy and Engagement (SOLE) scale items displayed on the linear logit scale.

teachers' knowledge of ocean science issues. That is, the items are reasonably well-targeted to the sample.

A review of the ordering of knowledge items from Rasch analysis suggests an interesting pattern of responses. Figure 1 presents part of the 54 ocean content knowledge items on the linear logit scale. Items at the top of the scale were the hardest ones for the participants to correctly answer. Those items at the base of the scale were the easiest ones to correctly answer. The ordering of ocean content knowledge revealed that participants had the most difficulty in correctly identifying the percentage of earth's water which is fresh and unfrozen (Figure 1, item 7). For this item, more than one-third of the students thought that it was between 20 and 30%, whereas only one-twentieth of the participants gave the correct answer (1%). Item 45 concerned the identification of deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. For this item, a significant percentage of pre-service teachers identified submarine hot springs as deep ocean ecosystems, that are independent of energy from sunlight and photosynthetic organisms, another significant group indicated both submarine hot springs and methane cold seeps, whereas most participants missed hydro-thermal vents. Two of the most difficult items (30 and 23) pertained to the earth's carbon cycle. For items 23 (% of carbon dioxide in the atmosphere absorbed by the ocean) and 30 (% of primary production on earth that takes place in the sunlit areas of the ocean), two incorrect options were often selected by respondents: approximately '30%' or '70%' (instead of the correct answer of '50%'). Contrary to these difficult-to-answer items, items 1, 19, and 21 were generally easy for respondents to answer. Out of these, item 19 (water cycle) was perceived as the easiest item to correctly answer (83% of the respondents). Also, most of the students in the sample were able to correctly identify that the ocean covers about 70% of the surface of our planet (item 1) and that surface temperatures would be more extreme than they are now, in case our planet were without its ocean (item 21).

Distractor analysis showed that the alternative response options of most items acted in the intended way, i.e. elicited responses that can discern a wide range of student ability. Table 3 summarizes distractor functioning (student response percentages and average ability of examinees selecting different distractors in logits) for a number of characteristic items. Positive logits represent persons with higher-than average overall ability and negative logits represent persons with lower-than-average overall ability. For items 7, 13 and 23, where response options involved percentages, response options close to 30% or 70% attracted a large number of answers. Specifically, it was observed that option (c) of item 7 ('20 to 30%'), option (d) of item 13 ('72%') and options (a) and (c) of item 23 ('30%' and '70%') were overly attractive options, selected by more than one-third of the respondents. For item 8 ('The ocean is connected to all the earth's water reserves (supplies) via …'), Table 3 shows that the students who correctly chose option (f) 'all of these' (12% of the total sample) had an average ability level of −0.21 logits. In contrast, students who incorrectly chose option (d) 'precipitation and evaporation' (30% of the total sample), and thus missed condensation, had a similar average ability level of −0.28 logits. In other words, a large percentage of students seem to ignore the role of condensation and are at a similar mean ability level with those who selected the correct answer. A similar pattern was observed in the case of item 27 ('By which process does the ocean lose heat that it absorbs from solar radiation?'), where students who incorrectly chose option (d) 'precipitation and evaporation' (18% of the total sample) had an

Table 3. Distractor analysis for the most characteristic items.

Item	Option	Score	%	Average (logits)	Item	Option	Score	%	Average (logits)
6					23				
	(c)	0	4	−1.13		(d)	0	10	−1.09
	(a)	0	2	−0.98		(c)	0	31	−0.50
	(b)	0	28	−0.80		(a)	0	39	−0.33
	(d)	0	2	−0.66		(b)	1	9	−0.22
	(e)	1	55	−0.16	27				
7						(b)	0	4	−0.85
	(a)	0	12	−0.85		(a)	0	5	−0.75
	(d)	0	16	−0.48		(e)	0	7	−0.70
	(c)	0	42	−0.36		(f)	0	13	−0.54
	(b)	0	10	−0.24		(d)	0	18	−0.21
	(e)	1	6	0.31		(c)	1	40	−0.18
8					43				
	(a)	0	6	−1.23		(c)	0	15	−0.86
	(b)	0	17	−0.55		(b)	0	17	−0.69
	(c)	0	10	−0.52		(a)	0	13	−0.66
	(e).	0	15	−0.46		(f)	0	16	−0.66
	(d)	0	30	−0.28		(d)	0	13	0.14
	(f)	1	12	−0.21		(e)	1	15	0.15
13									
	(b)	0	6	−0.95					
	(d)	0	37	−0.50					
	(c)	0	18	−0.41					
	(a)	0	8	−0.27					
	(e)	1	19	−0.07					

average ability level of −0.21 logits, very close to the average ability of students who chose the correct answer, (c) 'evaporation' (40% of the total sample), with an average ability of −0.18 logits. For item 6 ('What processes cause sea level changes?), the distractor (b) 'ice caps melt and grow' attracted a relatively large percentage of students (30%), who missed to recognize 'plate tectonics' and 'seawater expands and contracts' as additional contributors to sea level changes. Finally, for item 43 ('Which of the following causes vertical zonation patterns along the shore influencing the distribution and diversity of organisms?'), students who correctly chose option (e) 'all of these' (15% of the total sample) had an average ability level of 0.15 logits. In contrast, students who incorrectly chose option (d) 'both predation and tides' (13% of the total sample), and thus missed waves, had a similar average ability level of 0.14 logits.

Differential item functioning

Results of DIF analysis suggested that for a single item only, 37, 'What produces most of the earth's oxygen?', there appears to be a difference as a function of gender, with females exhibiting more difficulty in answering the item correctly (1.20 logits for females vs. 0.65 logits for males, DIF contrast = 0.51). No further action was taken as the level of DIF was relatively minor.

Discussion

The evaluation of the psychometric properties of the Greek version of the SOLE highlights the overall psychometric adequacy of the instrument. The revised SOLE demonstrated good internal consistency and constitutes a unidimensional scale. The former property indicates that the test is measuring a coherent general construct and the latter implies that there is a single dominant dimension underlying the 54 item responses, it provides further evidence for the convergence of all items to the construct being measured and is an indication of its construct validity. Unidimensionality is also suggested by the property of local independence, that is satisfied by the SOLE items and indicates that the probability of a correct response of an examinee (or all examinees of a given ability) to an item is unaffected by responses to other items in the test (Hambleton 1991).

The adopted SOLE effectively targets the ocean content knowledge of a typical group of pre-service teachers in Greece, distinguishing at least three ability levels; an upper-ability, a moderate-ability and a lower-ability stratum. This is in line with the study of Greely (2008), where at least three ability levels were also distinguished and it is a desirable feature for proper test functioning (Bond and Fox 2007). However, since test items were somewhat difficult for the pre-service teachers to endorse, the inclusion of easier items could provide a means of further improving measurement precision and, hence, sensitivity on the lower end of the trait continuum.

Item fit statistics and distractor analysis for each item identified no items that functioned poorly or were psychometrically redundant, but the Rasch DIF analyses indicated that one of the items functioned differently (from a measurement perspective) for males and females. This item captures an aspect of central importance, habitability, the only item in the scale related to this essential ocean principle (see Table 2) and the item was retained with no subsequent action. All other SOLE items were invariant by gender.

Most of the hardest and the easiest items of the present study also perplexed or facilitated respectively the respondents in the study conducted by Greely (2008). This consistency of the item-difficulty hierarchy between the two studies further supports the construct validity of the instrument. Particularly, respondents of both studies were familiar with some features of the ocean (its surface coverage on earth, the hydrological cycle, the transportation of nutrients, salts, sediments and pollutants from rivers to oceans) which are concepts frequently mentioned and widely discussed. On the other hand, they knew less about others (percentage of fresh and unfrozen earth's water, maximum depth of the ocean), which are mostly abiotic-related questions. Furthermore, the items about the carbon cycle which were the most difficult ones in the present study, concern complex biogeochemical concepts, that are not frequently encountered in the various grade levels in formal education. It has been argued that physical and chemical ocean concepts are difficult to be elaborated and differentiated (Brody 1996). Students' low knowledge on physical and chemical oceanography has been also supported by previous research (Cummins and Snivelly 2000; Ballantyne 2004; Guest, Lotze, and Wallace 2015).

As regards the distractors, the respondents' response behavior for the items concerning ocean connection to earth's water reserves and the process by which ocean loses heat that it absorbs by solar radiation, underline a gap in their knowledge of the concepts of evaporation, condensation and precipitation, which is consistent to other studies (Chang 1999; Gopal et al. 2004). The fact that respondents missed to recognize ‘plate tectonics’ as an additional contributor to sea level changes, probably ranks among the insufficient knowledge students have about plates and their motions (Marques and Thompson 1997; Libarkin et al. 2005). Furthermore, their response behavior to all the aforementioned issues, along with their lack of knowledge about the effect of seawater contraction and expansion on sea level changes and the effect of waves on vertical zonation patterns, indicates respondents’ essential lack of understanding of ocean processes.

To this point, it should be noted that multiple choice items can readily assess knowledge and be reliably and efficiently scored, but it is challenging to assess application and reasoning with this item format (Glynn 2012). Therefore, for improving the questionnaire, some of the multiple choice items that concern complex knowledge could be replaced by constructed response items. A constructed-response item is any test item requiring respondents to generate their own responses (Popham 2006, 185). Constructed response items can readily assess application and reasoning, while the greater complexity inherent in these items is consistent with a constructivist view of cognition, considering that constructing a response tends to be more cognitively demanding than choosing a response (Glynn 2012). These items will help reveal respondents’ level of model-based understanding of ocean systems and processes and how these systems connect to other earth systems; indeed, this type of knowledge is necessary for making informed decisions about important socioscientific ocean issues encountered in real life.

Along the same lines, taking into account that the Ocean Literacy Guide includes seven essential principles along with their fundamental concepts, accordingly, an instrument that measures ocean literacy should reflect all these principles. Therefore, the SOLE questionnaire could be further improved by adding items aligned with those essential principles that are not represented equally to others. Such principles are the ones that concern habitability of the ocean (Principle 4) and human connections to the ocean (Principle 6).

Overall, the SOLE, a concise instrument that draws upon all the essential principles and fundamental concepts of ocean literacy, constitutes a valid scale with acceptable internal consistency, and effectively targets the ocean content knowledge of high school students in the US (Greely 2008) and of pre-service teachers in Greece, according to the present study. These facts imply that this tool, after proper adaptation, could also be utilized for the assessment of ocean literacy in other cultural settings and target groups, such as high school students, university students, and pre- and in-service teachers. Considering that these groups constitute a considerable part of visitors in various non-formal educational settings, such as aquariums and museums, this tool could also be used so as to inform educational policy. Consequently, the instrument could indirectly advance the contemporary practice of environmental education in general.

Notwithstanding, there are some aspects of the questionnaire that could be further improved. Specifically, some of the SOLE items contain complex response options, such as ‘none of the above’, ‘all of the above’ and ‘both … and …’ or their combinations. However, some authors recommend against their use (Haladyna, Downing, and Rodriguez 2002; Rodriguez 2011) due to potential negative effects on an item’s ability to discriminate examinees. For instance, students can use analytic test-taking skills to eliminate or to choose these options. Although data analysis did not reveal any apparent effects of combination complex alternatives on item functioning, avoiding the use of such multiple-choice formats should be considered in a future revision of the SOLE instrument. Also, as suggested by one of the reviewers, one question (item 22) remains unclear and needs to be revised. A thorough literature review for this item revealed that there are conflicting sources with multiple different percentages, with the latest information underlining that natural oil seeps appear to be the most important source of oil that enters the ocean (NRC 2003; GESAMP 2007). Considering that this item is aligned with the sixth principle of ocean literacy, which concerns the interconnectedness between humans and the ocean, the question stem and the response options should be modified as follows: 'Which of the following anthropogenic sources puts the most oil in the ocean?' (a) oil spills from tankers (b) leaks from refineries and pipelines (c) operational discharges from ships (d) leaks from offshore oil rigs.

The present study has also limitations that should not be overlooked. All data was self-reported, and there was wide variation in the length of time it took students to complete the questionnaire. As with most research that relies on self-report, these factors raise the possibility of random and careless responding. Furthermore, it is possible that some of the students underperformed knowing that the test results will not affect their course grades. A marked questionnaire could serve as an incentive for them to provide more careful responses. Moreover, although the revised instrument was a result of a rigorous process that followed the methodological guidelines for cultural adaptation studies, the generalization of our findings to other target populations should be cautiously considered. Furthermore, ocean literacy, apart from knowledge, also involves attitudinal and behavioral components, all three of them being important in order for complete ocean literacy to be achieved. Future investigations could focus on the development of valid attitude and behavior instruments or the evaluation of established ones, as well as on their association with the SOLE. This could provide further evidence for the concurrent validity of the SOLE, which was not adequately addressed in this study.

In conclusion, our findings suggest that the SOLE constitutes a valuable tool which, after proper adaptation, can be transferred to different cultural contexts and populations. The proposed use of the instrument could contribute to the assessment of the quality of marine education in school-based and non-formal education contexts and to the cross-cultural comparison of ocean literacy, which are both prerequisites for the improvement of ocean literacy, as well as the advancement of environmental literacy in general.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Appendix 1. Greek version of the Survey of Ocean Literacy and Experience (in English)

(1) Approximately how much of the earth is covered by ocean?
(a) 30% (b) 50% (c) 60% **(d) 70%** (e) 90% (f) 97%
(2) There is one big ocean. The continents divide the ocean into basins. Which of the following are major ocean basins?
(a) Arctic, Red Sea, Atlantic, Pacific (b) Pacific, Gulf of Mexico, Atlantic, Mediterranean Sea (c) Pacific, Atlantic, Indian, Bering Sea **(d) Arctic, Pacific, Atlantic, Indian** (e) Pacific, Caribbean Sea, Atlantic
(3) Rivers supply most of the salt to the oceans, which comes from
(a) seafloor reactions **(b) eroding land** (c) volcanic emissions (d) atmosphere (e) all of these (f) none of these
(4) The movement of the earth's lithospheric plates influences an ocean basin's
(a) shape (b) features (islands, trenches) (c) color (d) size **(e) answers a, b and d**
(5) The ocean's circulation (currents) is powered by
(a) tides (b) winds (c) earth's rotation (d) both a and b **(e) answers a, b and c**

(6) What processes cause sea level changes?
(a) plate tectonics (b) ice caps melt and grow (c) seawater expands and contracts (d) sea level does not change **(e) answers a, b and c**
(7) Approximately how much of the earth's water is fresh and unfrozen (neither ice nor ocean)?
(a) >50% (b) 40–50% (c) 20–30% (d) 10–20% **(e) 1%**
(8) The ocean is connected to all the earth's water reserves (supplies) via
(a) condensation (b) precipitation (c) evaporation (d) b and c (e) none of these **(f) all of these**
(9) What approximately is the maximum depth of the ocean?
(a) 11km (b) 6km (c) 2.8km (d) 17km (e) 22km
(10) The ocean contains the earth's
(a) flattest plains (b) highest mountains (c) deepest valleys **(d) all are in the ocean** (e) none are in the ocean
(11) The path of ocean circulation is influenced by
(a) satellites (b) shape of ocean basins (c) adjacent land masses **(d) both b and c** (e) none of these
(12) The ocean is large and finite. Its resources are
(a) unlimited (b) all renewable (c) all nonrenewable **(d) limited** (e) answers a and b
(13) Approximately what fraction of the total water on earth is in the ocean?
(a) 42% (b) 34% (c) 52% (d) 72% **(e) 97%**
(14) Which of the following are transported by rivers from watersheds to estuaries and to the ocean?
(a) nutrients (b) salts (c) sediments (d) pollutants **(e) all of these** (f) answers b and d
(15) In nature, which factors redistribute sand along a beach?
(a) wave motion (b) coastal currents (c) tectonics (d) birds (e) plants **(f) answers a and b**
(16) Sea level changes over time have
(a) increased and decreased continental shelves (b) created and destroyed inland seas (c) shaped the surface of land **(d) all of these** (e) none of these
(17) Sediments are formed from erosion of land based earth materials. These include
(a) rocks (b) minerals (c) soils (d) plants and animals **(e) all of these** (f) none of these
(18) Climatic conditions constantly change and erode the landscape of barrier islands (beaches). Climatic changes occur in the form of
(a) heavy winds (b) wave action (c) tidal surges (d) coastal storms **(e) all of these** (f) none of these
(19) Water moves from the ocean to the atmosphere to the land and back again to the ocean by a process called
(a) watershed (b) hurricane **(c) water cycle** (d) tsunami (e) cyclone (f) perfect storm
(20) The physical structure and landforms of the coast are naturally influenced by
(a) sea level changes (b) force of waves (c) tectonic activity **(d) all of these** (e) none of these
(21) If our planet were without its ocean but otherwise the same as it is today, would surface temperatures be more extreme than they are now (warmer summers and colder winters) or less extreme, or what?
(a) more extreme (b) less extreme (c) no change in temperatures
(22) Which sources put the most oil in the ocean?
(a) oil spills from ships (b) leaks from refineries and pipelines **(c) evaporation from oil cargoes which returns to ocean by rain out** (d) leaks from offshore oil rigs (e) none of these sources put oil in the ocean
(23) The ocean dominates the earth's carbon cycle. Approximately how much of all the carbon dioxide in the atmosphere is absorbed by the ocean?
(a) 30% **(b) 50%** (c) 70% (d) 97%
(24) What is the essential nature of barrier islands?
(a) static and stability **(b) motion and change** (c) none of these

(25) All but one of the following decompose in ocean water
(a) sewage (b) tin cans **(c) plastic bags** (d) chemical fertilizers
(26) The ocean controls weather and climate by dominating which of the earth's systems?
(a) energy (b) plants (c) water (d) carbon **(e) answers a, c, and d** (f) none of these systems
(27) By which process does the ocean lose heat that it absorbs from solar radiation?
(a) precipitation (b) condensation **(c) evaporation** (d) both a and c (e) both a and b (f) all of these
(28) Most rain that falls on land originally evaporated from the
(a) tropical ocean (b) polar ocean (c) temperate ocean (d) rain does not begin in ocean e. none of these
(29) Global weather is changed by the El Nino Southern oscillation by changing the way heat is released in the atmosphere over which ocean basin?
(a) Atlantic **(b) Pacific** (c) Gulf of Mexico (d) Indian (e) Arctic (f) Red Sea
(30) The ocean dominates the earth's carbon cycle. Approximately how much primary production on earth takes place in the sunlit areas of the ocean?
(a) 30% **(b) 50%** (c) 70% (d) 97%
(31) The ocean has and will continue to have a significant influence on climate change by storing, absorbing, and moving
(a) salts (b) carbon (c) heat (d) water (e) plants **(f) answers b, c and d**
(32) The uneven heating of the earth's surface causes the ocean's temperature to vary with latitude. Which of the following is ordered from warmest ocean water to coldest ocean water?
(a) temperate to equator to poles (b) equator to poles to temperate (c) poles to temperate to equator (d) temperate to poles to equator **(e) equator to temperate to poles**
(33) Most of the living space on earth is found
(a) on the land **(b) in the ocean** (c) in the atmosphere (d) equally in all areas
(34) Pressure in the ocean increases with depth. What happens to temperature?
(a) increases with depth **(b) decreases with depth** (c) stays the same (d) increases and decreases (e) none of these
(35) What happens to sunlight in the ocean as depth increases?
(a) increases with depth **(b) decreases with depth** (c) stays the same (d) increases and decreases (e) none of these
(36) Where is a greater diversity of major groups of organisms found?
(a) on the land **(b) in the ocean** (c) both equally
(37) What produces most of the earth's oxygen?
(a) forests **(b) plants (algae) in the ocean** (c) both equally (d) none of these
(38) Which of the following groups of organisms would be more closely related?
(a) bony fish, jelly, seastar, crayfish (b) spider, crab, insect, mouse **(c) human, cat, dog, manatee** (d) alligator, shark, bonyfish, pelican
(39) Ocean life ranges in size from the smallest virus to the largest animal that has lived on earth, called the
(a) giant squid (b) basking shark **(c) blue whale** (d) sperm whale (e) Locness monster
(40) The most abundant life form in the ocean is
(a) seaweeds (b) fish (c) shrimps **(d) microbes** (e) marine mammals
(41) In the ocean living spaces and habitats are found
(a) at the surface (b) in the water column (c) on the seafloor **(d) all of these** (e) none of these
(42) Ocean habitats are defined by environmental factors. Life is not evenly distributed due to interactions of abiotic factors such as
(a) nutrients (b) sunlight (c) pH (d) oxygen (e) substrate **(f) all of these**
(43) Which of the following causes vertical zonation patterns along the shore, influencing the distribution and diversity of organisms?
(a) predation (b) waves (c) tides (d) both a and c **(e) all of these** (f) none of these

(44) Marine habitats that have brackish water and provide productive nursery areas for many marine species are
(a) seas **(b) estuaries** (c) rivers (d) open ocean (e) lagoons

(45) Deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms are
(a) hydrothermal vents (b) submarine hot springs (c) methane cold seeps (d) both b and c **(e) all of these**

(46) Which ocean ecosystem provides habitat for one-third of all marine species?
(a) coral reef (b) seagrass meadow (c) mangrove forest (d) open ocean (e) estuary

(47) The ocean is the last and largest unexplored place on earth. How much of the ocean remains unexplored?
(a) 30% (b) 50% **(c) greater than 90%** (d) less than 5% (e) 65%

(48) Why is it important to study the ocean?
(a) better understand ocean systems (b) satisfy our curiosity (c) understand ocean processes (d) not important to study the ocean **(e) answers a, b and c**

(49) Over the last 40 years, use of ocean resources has significantly increased. Why is it important to know this? So that we
(a) can do our part to sustain the resources (b) will discontinue ocean recreational activities (c) will better understand ocean resources and limitations (d) answers a, b and c **(e) both a and c**

(50) Which of the following statements are true about the ocean?
(a) it provides food and medicine (b) it provides mineral and energy resources (c) it provides transportation and jobs (d) it benefits economy **(d) all of these** (e) both c and d

(51) Ocean scientists are relying more and more on which of the following technology tools to explore the ocean?
(a) buoys (b) satellites (c) subsea observatories (d) unmanned submersibles **(e) all of these** (f) both c and d

(52) What does the statement 'the ocean and humans are inextricably connected' mean?
Humans need the ocean
(a) for freshwater (b) for oxygen (c) to regulate the temperature (d) for new health cures **(e) all of these**

(53) Humans affect the ocean in a variety of ways.
Human development and activity often leads to (a) pollution (point, non-point, noise) (b) physical changes to beaches (c) removal of most large vertebrates **(d) answers a, b and c** (e) humans do not affect the ocean

(54) Which natural hazards can impact coastal regions?
(a) bird migrations (b) hurricanes (c) storm surges **(d) both b and c** (e) none of these

Note: Correct answers are given in bold.