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What do Biologists Make of the Species Problem?

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Abstract The concept of species is one of the core concepts in biology and one of the cornerstones of evolutionary biology, yet it is rife with conceptual problems. Philosophers of biology have been discussing the concept of species for decades, and in doing so they sometimes appeal to the views of biologists. However, their statements as to what biologists think are seldom supported by empirical data. In order to investigate what biologists actually think about the key issues related to the problem of species, we have conducted a survey on the sample of 193 biologists from the population of biologists from over 150 biology departments at universities in the US and the EU. This article presents and discusses the results of the survey. Some results confirm and others falsify the reiterated statements of philosophers of biology as to what biologists think, but all results we obtained should be informative and relevant for future discussions of the problem of species.

Keywords Species concept · Unit of evolution · Problem of universals · Ontological status of species

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1 Introduction

"Species are to biologists what notes are to musicians. Everything in biology revolves around them," wrote a respected biologist in his book on speciation (Schilthuizen 2001). However, there are many problems with the very concept of species. Does a species exist as something over and above individual organisms that share certain features? If not, is the term that we use for a particular species merely a word, then, an arbitrary pigeon-hole that we create to cope with nature's diversity? Or, agreeing that it is a creation of ours, perhaps we should insist that it is not an arbitrary construct, but one that adequately reflects nature's seams, which explains why the concept of species is indispensable? This is the old philosophical problem concerning the status of universals—whether species are real entities, arbitrary linguistic conventions that we use to refer to reality, or concepts that adequately reflect reality—which define the positions of realism, nominalism and conceptualism. These positions can be usefully mapped on the literature dealing with the species problem: realism is defended, for example, by Stamos (2003), Lee (2003), Holter (2009), Lehman (1967), Brigandt (2003), Ruse (1992), Richards (2010) and Wilkins (2003); nominalism is defended by Mishler and Donoghue (1994), Stanford (1995), Ereshefsky (1998), Burma (1949) and Shaw (1969), whereas conceptualism is defended by Bessey (1908), Van Regenmortel (2007), Mahner (1993), Mahner and Bunge (1997). Treating this question as a part of the traditional problem of universals has already been argued for in full complexity by Stamos (2003) and Richards (2010).

One's take on the question of universals might have a bearing on the more specific question concerning the nature of species, i.e. what sort of thing is a species? Is it an individual, a class, or perhaps a cluster class? Answers to these questions define the dominant positions on another aspect of the species problem, that is the question concerning the ontological status of species (Caplan 1980; Ereshefsky 2010a, b; Pigliucci 2003; Richards 2010; Stamos 2003; Wilson 1999).

Regardless of how one answers either of the two preceding questions, there is another big question: how does one decide which organism belongs to which species? Different biologists will reply differently to this question, using different criteria of species membership, often depending on the branch of biology in which they work. However, if there are different criteria of species membership, clearly there are different concepts of species, each with its own definition that specifies the criteria of species membership (cf. Hey 2001, 2006). And if there are different concepts of species, how do we decide if they are all concepts of *species*? If we cannot decide that question, the very category of species seems to be heterogeneous and possibly incoherent. Indeed, Reydon (2005), for instance, argues that there four different types of species concepts, each based on a different ontology and addressing a different task in biology. Is it even reasonable, then, to hope for a single concept of species applicable to all organisms? This is what motivates the question of monism versus pluralism regarding species.

In tackling these questions, leading contributors to the field of philosophy of biology tend to make general claims about the role of the concept of species in

biology or about the prevailing views of biologists concerning the concept of species, without offering any empirical support for such claims. Here is a sample of 10 such claims:

(a) The species concept is a fundamental concept in biology (Ereshefsky 1992a, 2010a; Pavlinov 2013; Richards 2010; Schilthuizen 2001).
(b) The species is the fundamental unit of evolution (Ereshefsky 1992b, 2010a; Mayr 2000; Richards 2010).
(c) The question of species concepts is of great importance in biology (Wheeler and Meier 2000).
(d) Biologists think that species are real entities (Ereshefsky 1992b; Coyne and Orr 2004; Mayr 1996; Richards 2010; Ruse 1992).
(e) Species as individuals is a dominant position on the ontological status of the species (Ereshefsky 1992b, 2010a, b; Ghiselin 1992; Sterelny 1999).
(f) The position that species are individuals implies that species really exist (Ghiselin 1992).
(g) Species essentialism is not a plausible position in modern biology (Ereshefsky 2010a; Devitt 2008; Dupre 1999; Richards 2010).
(h) Species monism implies that species really exist (Hull 1999; Richards 2010; Wilkins 2003).
(i) Species pluralism implies that species do not really exist (Hull 1999; Wilkins 2003).
(j) Most biologists use the biological species concept in their research (Claridge 2009).

To check the validity of these and related claims, we conducted a survey among biologists from over 150 universities in the US and the EU. To the best of our knowledge, this is the first such survey on the topic.

Before we explain the methodology and present the results, we should like to make two preliminary points. First, this approach is based on the tenets of experimental philosophy which "challenges the truth of beliefs that are generally held, ones traditionally important in philosophy" (Sosa 2008). In this particular case, we challenge the truth of some beliefs that are generally held by philosophers of biology and that happen to be crucial for the problem of species. Secondly, we opted for this approach because the available literature was uninformative as to the empirical evidence for the beliefs of philosophers of biology about the role of the concept of species in biology and about the prevailing views of biologists concerning the concept of species. We assumed that the actual views of biologists can be established empirically and that the obtained results would constitute valid evidence in support or rebuttal of the beliefs of philosophers of biology concerning the problem of species.

We are aware that the results of this research do not provide us with definitive answers to the problem of species, but we believe that they can nevertheless be of use to both biologists and philosophers of biology—to biologists, because our survey might help them to reflect on the concept of species as one of the fundamental concepts in biology, and to philosophers of biology, because the results

obtained will be informative, or at least indicative, of what biologists actually think about the key issues pertaining to the problem of species. Efforts on both sides, we hope, might contribute to a more coherent, empirically grounded and widely accepted use of the concept of species.

2 Methods

For the purpose of answering the questions related to the spread of specific views and shared understandings related to the species problem among biologists, we chose quantitative methodology and an online survey as our method. The questionnaire we used as the instrument for data gathering was created with the online software survey tool Qualtrics (http://www.qualtrics.com/).

The targeted population of this survey were academics in the field of biology and PhD students of biology at universities in the EU and the US. We tried to obtain results by using the probabilistic cluster sampling technique. We randomly selected 20 universities with biology departments from the pool of over 1200 universities in the EU and the US. After initial difficulties with navigating departmental web-sites in different languages and finding the contacts, we sent an e-mail written in English in which we asked the heads of the departments to take a 10-min survey, but also to help us recruit other biologists, doctors of biology and PhD students of biology from their departments by forwarding the link provided in the e-mail. After three weeks, the survey was completed by only 7 participants.

Realizing that the cluster sampling technique will not give us the requisite number of results, we decided to use the snowball sampling technique. It is a technique in which a certain number of participants, used as initial seeds, recruit future participants among their colleagues and acquaintances. We opted for this technique for the following reasons. First, we estimated that an electronic online survey distributed through personal channels would have a significantly higher turnout rate than if we attempted to reach each potential participant individually, for the well-known difficulties with obtaining correct e-mail addresses of potential participants, passing the recipients' spam filters, and then receiving feedback on a query from an unknown sender. Second, the snowball sampling technique crucially relies on personal networks of scholars, with the result that it can provide reliable data on small and specific populations such as the population of biologist and biologists to-be (Crane 1969; Biernacki and Waldorf 1981; Atkinson and Flint 2001). Third, the snowball sampling technique is cost efficient. Of course, the snowball sampling technique has its limitations, which we briefly discuss below in Sect. 6.

The data was collected over a period of ten weeks in the first half of 2014. As seeds, or starting points in our snowball sampling, we sent an e-mail with the request for participation in the survey to the heads of biology departments in universities from the EU and the US listed in Appendix. Informed by our experience with the cluster sampling technique and the extremely low turnout rate, we created a list of the starting points in our snowball sampling by going through the initial list of 1200 universities and selecting those that had clear and straightforward information

about their biology departments on the web, in English as the default or optional language, with immediately accessible contacts of the heads of the biology departments.

In the initiation e-mail, we asked the heads of the biology departments to take a 10-min survey, but also to help us recruit other biologists, doctors of biology and PhD students of biology known to them—not necessarily from their own department—by forwarding the link provided in the e-mail. We also informed the respondents of the purpose and goals of our research project and survey, and we covered issues related to research ethics, such as confidentiality, the sort of information collected in the questionnaire and the sole purpose of doing so.

As a result of the snowball sampling technique, a total of 193 participants have at least partially filled in the survey questionnaire, with 151 participants completing the survey and 42 participants quitting the survey questionnaire. This explains the difference in the number of participants that answered the questions about gender, academic/scientific position and years spent in research, located at the end of the survey, and the number of participants that answered the questions about the branch in biology in which they work and the sorts of organisms on which they conduct their research which were at the beginning of the survey. For detailed information about the population, see Supporting information.

The final sample is satisfactory in terms of the demographics of respondents. As can be discerned from Supporting information, the achieved sample offers a balanced glimpse into the attitudes of biologists at different stages of their careers and of different specializations, though not in geographical distribution (see Sect. 6 below). From this result, and by acknowledging that snowball sampling is an interactional sampling technique, we recognize the finding of Crane (1969) that networks of scientists are highly diversified and that by interactional sampling we can cover main diversities within the population. The demographics of our sample, together with the presented theoretical and previous research findings, allow us to think that the population of biologists is reasonably well represented in our research, and that our results provide sufficiently reliable information on the important trends related to the views attitudes on the species problem held by biologists on the key aspects of the problem of species.

In the questionnaire, operationalized to meet the goals of the survey, we used only nominal variables in the form of multiple-choice questions. With the exception of Question 5, participants had to choose a single answer they thought was the correct one. In all questions in which it was possible, depending on the construction of the question, we added the option “I don’t know” or “Other”. The answer “Other” was followed by a box allowing data input by the survey participant.

3 Results

The purpose of the introductory questions was to identify the branches of biology in which our participants work and types of organisms on which they conduct their research. For detailed results on these questions refer to Supporting information above. Following the introductory questions, the first core question of our research

was: (1) "The unit of evolution is…". With this question we wanted to see if biologists in fact think that the species is the unit of evolution, as is sometimes claimed in the literature on the species problem (Ereshefsky 1992b, 2010a; Mayr 2000; Richards 2010). However, only 7.39% of participants think that species is the unit of evolution. The two most common answers are that the unit of evolution is gene (35.79%) and population (34.6%). Seven participants (3.98%) answered that evolution can take place at multiple levels of biological hierarchy. Five participants opted for "Other". Based on the results presented in Table 1, it is safe to conclude that most biologists do not think that the species is the unit of evolution.

The next question, (2) "Do you think that the concept of species is one of the basic concepts in biology?", aimed to check if biologists think that the species is one of the fundamental concepts in biology, as is often claimed in the literature on the species problem (Ereshefsky 1992a, 2010a; Pavlinov 2013; Richards 2010). 83.53% of our participants indeed think that the species is one of the fundamental concepts in biology. 11.94% of our participants think that the species is not one of the fundamental concepts in biology, and 4.55% of participants did not know how to answer the question. It is safe to conclude that most biologists do think that the species is one of the fundamental concepts in biology. More information about the answers to this question in Table 2.

Since most biologists think that the species is one of the fundamental concepts in biology, we wanted to see which criterion for grouping organisms into species our participants considered most important, so we asked them the following question: (3) "In your opinion, how are organisms grouped into species?" It is clear from the answers to this question that the criteria of reproductive isolation and phylogeny were considered the most important ones. On the other hand, only three participants noted that they were using ecological niche and overall phenotypic similarity as the criteria for grouping organisms into species. It is interesting that 10 participants pointed out that they use multiple criteria for grouping organisms into species and 12 participants had chosen the answer "Other". More information about the answers to this question in Table 3.

Table 1 What is the unit of evolution?

Unit of evolution is:	Number of responses
Gene	63
Organism	22
Deme	3
Population	60
Species	13
Evolution can take place on multiple levels of biological hierarchy	7
Other	5
I don't know	3
Total	176

Table 2 The importance of the concept of species

Do you think that the concept of species is one of the basic concepts in biology?	
Answer	Number of responses
Yes	147
No	21
I don't know	8
Total	176

Table 3 Criteria for grouping organisms into species

Answer	Number of responses
Reproductive isolation	62
Morphology	11
Phylogeny	53
Genealogical concordance	14
Ecological niche	1
Overall phenotypic similarity	2
Gene flow	11
Multiple criteria	10
Other	12
Total	176

With question (4) "Which species concept do you most often use in your research?", we wanted to outline different concepts of species according to the frequency of their use by biologists in their respective fields of research. Based on the answers to Question 3, we expected that the biological and the phylogenetic species concept will be the most frequently used ones, since the criteria of reproductive isolation and phylogeny are considered the most important criteria for grouping organisms into species. The results met our expectations, as they show that the biological species concept is the most frequently used concept by biologists in their research, with 31.61% of our participants opting for this answer. The second most frequently used species concept is the phylogenetic species concept, with 17.42% of our participants subscribing to it. There are two things to note here: first, 12.26% of our participants reported that they do not use *any* species concept in their research, and second, none of our participants reported to use the phenetic species concept in their research. More information about the answers to this question in Table 4.

To see what is the distribution of the use of different species concepts among biologists working in different branches of biology, we cross-referenced the answers to question (4) with answers from Supporting information about the branches of biology in which our participants work. This cross-referenced data is presented in Table 5.

With question (5) "Which other species concepts, to the best of your present knowledge, are used in biology?" we wanted to ascertain which other species

Table 4 Species concepts used by biologists

Which species concept do you most often use in your research?	
Species concept	Number of responses
Biological species concept	49
DNA barcode[a]	4
Ecological species concept	5
Evolutionary species concept	14
Genic species concept	5
Morphological species concept	16
Phenetic species concept	0
Phylogenetic species concept	27
Taxonomic species concept	8
Other	8
I don't use any species concept	19
Total	155

[a] Strictly speaking, DNA barcode is not a concept of species, but we included it in our list because the DNA barcoding technique contains a set of well-defined criteria for species membership, which may be regarded as a proxy for a definition of a distinct species concept

concepts, in addition to their most frequently used one, biologists are acquainted with. Unlike all the other questions in the survey, the participants could pick multiple answers here. The largest number of participants (Table 6), a total of 101 of them, reported to be familiar with the phylogenetic and the biological species concept as a close runner-up, with 96 answers of our participants. More information about the answers to this question in Table 6.

The answers we obtained to questions (4) and (5) gave us a good indication regarding the views of biologists on the issue between monism and pluralism regarding the species concept, suggesting that pluralism would be the default position of biologists, since multiple species concepts are being used by the community of biologists. This is confirmed by the answers obtained to Question (6), "Do you think that there is a single species concept applicable to all branches of biology?" In this question monism was presupposed by the affirmative answer, while pluralism was presupposed by the negative answer. From the results we have gathered (Table 7), it is easy to conclude that a large majority of biologists, that is 80% of our participants, think that a single species concept applicable to all branches of biology does not exist, which implies that most biologists believe that monism is false. Only 13.55% of our participants think that a single species concept applicable to all branches of biology does exist, which makes monism a small minority view. More information about the answers to this question in Table 7.

Even if pluralism is the default position in the community of biologists, we wanted to see whether monism is nevertheless a desideratum. So, the intention of question (7), "Would it be desirable to have a single species concept applicable to all branches of biology?", was to investigate whether biologists believe that, even if a single species concept applicable to all branches of biology does not exist, it would be good to have one. The affirmative answer to this question essentially presupposes that monism would be a desirable position, while the negative answer presupposes that it would not. It is apparent from the results (Table 8) that 51.62%

Table 5 Cross-referenced data between Question (4) Which species concept do you most often use in your research and question from Supporting information: In which branch of biology do you work?

In which branch of biology do you work?									
		Bioinformatics	Botany	Cell biology	Conservation biology	Ecology	Epigenetics	Marine biology	Microbiology
Which species concept do you most often use in your research?	Biological species concept	0	1	2	2	18	1	1	2
	DNA barcode	0	0	0	0	0	0	0	2
	Ecological species concept	0	0	0	0	1	1	0	0
	Evolutionary species concept	1	1	2	0	1	1	0	3
	Genic species concept	0	0	1	0	0	0	0	2
	Morphological species concept	0	0	2	0	6	0	1	1
	Phenetic species concept	0	0	0	0	1	0	0	0
	Phylogenetic species concept	2	2	1	0	0	0	1	6
	Taxonomic species concept	0	0	0	0	4	0	0	1
	Other	0	1	0	1	0	0	0	2
	I don't use any species concept	2	0	2	0	3	0	0	0
	Total	5	5	10	3	35	3	3	19

Table 5 continued

In which branch of biology do you work?									
		Molecular biology	Mycology	Neurobiology	Physiology	Virology	Zoology	Other	Total
Which species concept do you most often use in your research?	Biological species concept	2	0	0	3	0	7	10	49
	DNA barcode	1	0	0	1	0	0	0	4
	Ecological species concept	1	0	0	0	0	1	1	5
	Evolutionary species concept	0	0	0	0	1	2	2	14
	Genic species concept	2	0	0	0	0	0	0	5
	Morphological species concept	0	1	0	0	0	2	3	16
	Phenetic species concept	0	0	0	0	0	0	0	1
	Phylogenetic species concept	5	0	1	1	0	1	4	26
	Taxonomic species concept	0	0	1	0	0	1	1	8
	Other	0	0	1	0	0	2	1	8
	I don't use any species concept	2	0	3	2	0	0	5	19
	Total	13	1	6	1	1	16	27	154

Table 6 Other species concepts known to biologists

Which other species concepts, to the best of your present knowledge, are used in biology?			
Species concept	Number of responses	Species concept	Number of responses
Agamospecies concept	1	Internodal species concept	1
Biological species concept	96	Least inclusive taxonomic unit	8
Biosimilarity species concept	8	Management unit	17
Cladistic species concept	58	Morphological species concept	70
Cohan's ecological concept	2	Nothospecies	0
Cohesion species concept	14	Phenetic species concept	18
Compilospecies concept	0	Phylogenetic species concept	101
Composite species concept	3	Phylo-phenetic species concept	7
DNA barcode	45	Polythetic species concept	2
Ecological species concept	75	Recognition species concept	14
Evolutionary species concept	74	Recombination species concept	3
Genealogical concordance principle	15	Reproductive competition species concept	7
General lineage concept of species	12	Successional species concept	4
Genic species concept	17	Taxonomic species concept	54
Genotipic cluster definition	13	Other	9

Table 7 The problem of monism versus pluralism

Do you think that there is a single species concept applicable to all branches of biology?	
Answer	Number of responses
Yes	21
No	124
I don't know	10
Total	155

of our participants think that monism is not a desirable position in the species problem, 32.9% think that it is, whereas 15.48% did not know whether monism is desirable or not. We find this result interesting because it indicates that a significantly greater number of biologists think that having a single species concept applicable to all branches of biology would be desirable than the number of biologists who think that there is such a concept. More information about the answers to this question in Table 8.

With question (8), "Species are…", we wanted to examine which position in the debate on the ontological status of species is the most common one among biologists. Our results show that the weakest position by far is that species are

Table 8 Desirability of monism

Would it be desirable to have a single species concept applicable to all branches of biology?	
Answer	Number of responses
Yes	51
No	80
I don't know	24
Total	155

Table 9 The problem of the ontological status of species

Species are	
Ontological status of species	Number of responses
Individuals	5
Entities whose members have one or more common traits necessarily possessed by each and every member of the species	84
Entities whose members have one or more common traits, but none of them is necessarily possessed by each and every member of the species	76
I don't know	5
Total	170

individuals, with only 2.94% of our participants subscribing to it. The strongest position on this issue is that species are classes, with 49.43% of participants opting for this position. The position that species are cluster classes—represented by the answer "Entities whose members have one or more common traits, but none of them is necessarily possessed by each and every member of the species"—was chosen by 44.7% of our participants. More information about the answers to this question in Table 9.

Question (9), "Which of the following statements best expresses your understanding of species?", was intended to investigate the views of biologists on the question of universals regarding the species. Each of the answers offered to our participants assumed one of three classic positions in the problem of universals: realism, conceptualism and nominalism. The first answer, "Species are real entities" captured the position of realism, the second answer "Species are not real entities, but concepts that adequately represent groups of organisms" captured the position of conceptualism, and the third answer "Species are neither real entities nor concepts, but mere labels convenient for distinguishing groups of organisms" captured the position of nominalism. The latter two positions can be subsumed under the common term "anti-realism", which means that neither conceptualism nor nominalism implies that species exist as real entities over and above individual organisms. 40.1% of our participants think that realism is the correct position, while

Table 10 The problem of universals

Which of the following statements best expresses your understanding of species?	
Understanding species	Number of responses
Species are real entities	70
Species are not real entities, but concepts that adequately represent groups of organisms	71
Species are neither real entities nor concepts, but mere labels convenient for distinguishing groups of organisms	28
I don't know	3
Total	172

57.56% think that anti-realism is the correct position. Among the anti-realists, 41.28% of the participants prefer conceptualism, and only 16.28% opt for nominalism. These results show that anti-realism is the prevalent position among biologists, with conceptualism as the most popular position, realism as a tight runner-up, and nominalism as the position with fewest supporters. More information about the answers to this question in Table 10.

4 Discussion—Part I

We would like to provide a comparative data analysis of the obtained results in order to elucidate some common attitudes in the literature on the species problem. The position of realism—the view that a species exists as something over and above individual organisms that belong to this species—is often connected with the position that species are individuals. Cross-referenced data in Table 11(A) represents one position in the debate concerning the ontological status of species and connects it with three major positions concerning the universals. Table 11(A) shows how the participants who answered question (9) answered question (8). This is cross-referenced data for questions "Which of the following statements best expresses your understanding of species?" and "Species are…". The cross-referenced data in Table 11(A) indicates that, of all participants who think that species have the ontological status of individuals, only one participant thinks that species are real entities, three think that species are not real entities, but concepts that adequately represent groups of organisms, and only one thinks that species are neither real entities nor concepts, but mere labels convenient for distinguishing groups of organisms.

Table 11(A) also shows that, of all participants who think that species are cluster classes (entities whose members have one or more common traits, but none of them is necessarily possessed by each and every member of the species), 33 participants think that species are real entities, 29 think that species are not real entities, but concepts that adequately represent groups of organisms, and 11 think that species

Table 11 Cross-referenced data between: (A) Questions (9) "Which of the following statements best express your understanding of species?" and (8) "Species are…"; (B) Questions (8) "Species are…" and (6) "Do you think that there is a single species concept applicable to all branches of biology?"; (C) Questions (9) "Which of the following statements best express your understanding of species?" and (6) "Do you think that there is a single species concept applicable to all branches of biology?"

(A) Question (9) "Which of the following statements best express your understanding of species?"

	Species are real entities	Species are not real entities, but concepts that adequately represent groups of organisms	Species are neither real entities nor concepts, but mere labels convenient for distinguishing groups of organisms	I don't know	Total
(8) "Species are":					
Individuals	1	3	1	0	5
Entities whose members have one or more common traits necessarily possessed by each and every member of the species	32	37	14	0	83
Entities whose members have one or more common traits, but none of them is necessarily possessed by each and every member of the species	33	29	11	3	76
I don't know	2	2	1	0	5
Total	68	71	27	3	169

(B) Question (8) "Species are":

	Individuals	Entities whose members have one or more common traits necessarily possessed by each and every member of the species	Entities whose members have one or more common traits, but none of them is necessarily possessed by each and every member of the species	I don't know	Total
(6) "Do you think that there is a single species concept applicable to all branches of biology?"					
Yes	0	11	10	0	21
No	4	59	55	5	123
I don't know	0	4	6	0	10
Total	4	74	71	5	154

Table 11 continued

(C) Question (9) "Which of the following statements best express your understanding of species?"					
	Species are real entities	Species are not real entities, but concepts that adequately represent groups of organisms	Species are neither real entities nor concepts, but mere labels convenient for distinguishing groups of organisms	I don't know	Total
(6) "Do you think that there is a single species concept applicable to all branches of biology?"					
Yes	13	5	3	0	21
No	48	55	19	1	123
I don't know	3	4	1	2	10
Total	64	64	23	3	154

are neither real entities nor concepts, but mere labels convenient for distinguishing groups of organisms.

Cross-referenced data in Table 11(A) also indicates that, of all participants who think that species are classes (entities whose members have one or more common traits necessarily possessed by each and every member of the species), 32 participants think that species are real entities, 37 think that species are not real entities, but concepts that adequately represent groups of organisms, and 14 think that species are neither real entities nor concepts, but mere labels convenient for distinguishing groups of organisms.

These findings suggest that biologists who hold the position that species are real entities do not subscribe to the position that species are individuals, contrary to what is often claimed in the literature on the species problem (Ereshefsky 1992b, 2010a; Ghiselin 1992; Sterelny 1999).

In the literature on the species problem, Mayden (1997) makes a strong connection between monism and the idea that species are individuals. Table 11(B) explores the strength of this connection. Table 11(B) shows how the participants who answered question (8) answered question (6). That is cross-referenced data for questions "Species are…" and "Do you think that there is a single species concept applicable to all branches of biology?".

Table 11(B) shows how the participants who answered question (8) answered question (6). Cross-referenced data in Table 11(B) indicates how many proponents of monism hold one of the positions according to which species are individuals, classes or cluster classes and how many proponents of pluralism hold one of the positions according to which species are individuals, classes or cluster classes.

An in-depth analysis is not required here because it is immediately apparent that not a single proponent of monism holds the position that species are individuals, while all four proponents of the position that species are individuals think that pluralism is the correct account of the species in the debate between monism and pluralism. This indicates very strongly that there is no connection between monism and the position that species are individuals, at least not in the minds of trained biologists that we have surveyed.

With this comparative data analysis Table 11(C) we wanted to see if there is any connection between monism and realism on the one hand, and pluralism and anti-realism (conceptualism and nominalism) on the other hand, as is often claimed (Hull 1999; Richards 2010; Wilkins 2003). Table 11(C) shows how have the participants who answered question (9) answered question (6). That is cross-referenced data for question "Which of the following statements best express your understanding of species?" and question "Do you think that there is a single species concept applicable to all branches of biology?". Cross-referenced data in Table 11(C) indicates that, of all participants who think that there is one correct species concept applicable to all branches of biology, 13 participants also think that species are real entities, 5 think that species are not real entities, but concepts that adequately represent groups of organisms, and 3 think that species are neither real entities nor concepts, but mere labels convenient for distinguishing groups of organisms.

Data in Table 11(C) also suggests that, of all participants in this survey who think that a single correct species concept does not exist, 48 participants believe that

species are real entities, 55 that species are not real entities, but concepts that adequately represent groups of organisms, and 19 that species are neither real entities nor concepts, but mere labels convenient for distinguishing groups of organisms.

These results suggest, if our survey is taken as representative, that a little more than a half of biologists who think that species are real entities also believe that there is one correct species concept applicable to all branches of biology. This offers some support to authors who think that monism and realism are strongly connected, though the connection is not nearly as strong as these authors suggest (Hull 1999; Wilkins 2003; Richards 2010). On the other hand, we can see that, among the total number of proponents of pluralism, 48 of them think that realism is the correct position for understanding species, and 74 of them think that one of the anti-realist positions is the correct one for understanding species. While it is true that more than a half of the proponents of pluralism hold one of the anti-realistic positions, it is also true that as many as 39.34% of the proponents of pluralism believe that species are real entities. We think that this finding casts some doubt on the claim that pluralism and anti-realism are closely connected.

5 Discussion—Part II

In this part we would like to examine some of the findings of our survey that we find most surprising, and hence most interesting.

Answers to Question (1) "The unit of evolution is…" (Table 1) were rather unexpected. In the literature on the species problem it is often claimed that the species is the unit of evolution (Ereshefsky 1992b, 2010a, b; Mayr 2000; Richards 2010). From the results of this survey, however, it follows that only a minority of biologists would subscribe to that claim, which should give philosophers of biology a pause. What surprised us even more was the fact that most biologists, 123 out of 176 participants, were divided between the view that the unit of evolution is gene (63 participants) and population (60 participants). Contrary to our expectations, this result suggests that this issue is not yet a settled matter in contemporary biology.

Answers to Question (9), "Which of the following statements best expresses your understanding of species?" (see Table 10), indicate that biologists are divided also over the question whether species are real entities or not. The two anti-realist positions—conceptualism and nominalism—are more widespread than realism. Of 172 participants that answered this question, 70 think that species are real entities, while 99 think that they are not (with three undecided participants). Although realism and conceptualism gained almost equal support, 71 participants think that species are not real entities, but concepts that adequately represent groups of organisms, whereas nominalism is the least supported position, with only 28 votes. The impression we get from these results is that the community of biologists is not clear as to whether species are real entities or not.

The biggest surprise to philosophers of biology will probably be answers to Question (8) "Species are…", where the given options were: individuals, classes or cluster classes. We assumed that it would be important to test the views of biologists

on this question because in the literature on the species problem the prevailing view seems to be that species are individuals (Ereshefsky 1992b, 2010a; Ghiselin 1992; Hull 1992; Mayden 1997; Stamos 2003; Sterelny 1999; Wiley and Mayden 2000). Our results indicate that this position is utterly marginal, with only 5 out of 170 of participants subscribing to it (2.9%). Most of our participants were divided between the positions that species are classes or cluster classes (Table 9). It would be interesting to investigate why philosophers of biology are so deeply convinced that species are individuals, contrary to the view of biologists, but also why biologists find the same position so unpalatable.

Question (4), "Which species concept do you most often use in your research?", in conjunction with Question (5), "Which other species concepts, to the best of your present knowledge, are used in biology?", were designed to identify the predominant species concept among biologists. Question (4) focused on the species concept that was *actually* used by our participants in their research. It turns out that only about a third of biologists use the biological species concept, which indicates that its importance in contemporary biology should not be overestimated. Question (5) focused on the species concept that our participants *think* is used in contemporary biology. All species concepts that we offered were believed to be in use in contemporary biology, except for the concepts of compilospecies and nothospecies. Among our participants, 101 of them believed that some form of phylogenetic species concept is used, and 96 took the biological species concept to be used in biology (Table 6).

We think that the answers to Questions (4) and (5) should be taken together as strong evidence against monism, since they clearly indicate that there is more than one species concept in use in contemporary biology. It is very likely that the use of particular species concepts varies with different fields of biology, although this issue requires more investigation. A further blow to monism is apparent from the answers obtained to Question (6), "Do you think that there is a single species concept applicable to all branches of biology?", and Question (7), "Would it be desirable to have a single species concept applicable to all branches of biology?" As for Question (6), 80% of our participants think it false that there is one species concept applicable to all fields in biology (Table 7). Regarding Question (7), more than a half of our participants think that monism is not even a desirable position in biology (Table 8). We take these results to pose a serious challenge to monism. It shows that a generally applicable species concept is not available (Kunz 2002), at least as far as the views of biologists are concerned.

Another big surprise to philosophers of biology is likely to be found in our results presented in Table 11(A). The comparative data analysis between Question (9), "Which of the following statements best expresses your understanding of species?", and Question (8), "Species are…", suggest that biologists do not see a connection between realism and the status of individuals. Alternatively, it is possible that biologists lack the understanding of what philosophers mean by "individual", which may require further exploration. It is suggested from the obtained answers that out of 66 proponents of realism only one thinks that species are individuals, whereas the other 65 happily connect realism with the view that species are classes or cluster classes.

Finally, there seems to be no connection whatsoever between the position that species are individuals and monism, as shown in Table 11(B). Our results show that the four proponents of the position that species are individuals do not think that there is one correct species concept applicable to all branches of biology.

The results of our survey and the conclusions drawn in the preceding discussion allow us to put forward some more general statements. First, philosophers of biology should be more cautious in their pronouncements as to what trained biologists think about different aspects of the species problem, not least because biologists do seem to share the same understanding of the key concepts and their philosophical implications. Second, the search for a single species concept applicable to all branches of biology should perhaps be abandoned for a more detailed investigation of the species concepts that biologists actually use in their research, exploring the abstract conceptual underpinnings of their use and possible natural propensities of particular branches of biology towards particular species concepts. We believe that this refocusing might be instrumental to facilitating the work of biologists in classifying organisms, but it might also lead to a welcome reduction of the number of species concepts in circulation. Third, it appears that study programs in biology should include at least some basic training in philosophical concepts and issues related to species and classification.

6 Conclusion

The results presented in this research allow only tentative conclusions, for three main reasons. First, the snowball sampling technique relies on personal networks, which makes the results obtained with that technique inherently biased. Second, the technique gives researchers no control over the process, which may yield results that do not cover the targeted population evenly. Third, our results turned out to be biased towards the participants from the US, because our choice of the initial seeds was guided by considerations of language and information availability, as explained in Sect. 2 above. This geographic bias could not be repaired post hoc. We were unable to repeat our survey with the aim of obtaining more results from biologists working in the EU, because the snowball sampling technique gives no guarantee that this aim would in fact be achieved, and more importantly, because we could not prevent an unknown number of individuals from receiving and completing the survey twice over, thus effectively compromising the quality of the results we have obtained in the first round.

Notwithstanding the limitations of our results, we believe that our survey will be of use to both biologists and philosophers of biology. We did manage to obtain a sample that offers a balanced glimpse into the attitudes of biologists at different stages of their careers. As can be seen from Supporting information, we got participants from all stages of academic career ranging from novices to over 20 years spent in research, from PhD students to full professors. If we look at our participants based on the branches of biology in which they work, it is apparent that we covered biologists from 14 different specializations, ranging from bioinformatics to zoology. Though imperfect, the snowball sampling technique is said to provide

reasonably reliable data on small and specific populations such as the population of trained biologists (Crane 1969; Biernacki and Waldorf 1981; Atkinson and Flint 2001), and to cover main varieties within highly diversified populations such as networks of scientists (Crane 1969). Although the results obtained with this technique cannot be generalized without due qualifications, we believe that the results presented in this paper are indicative enough to merit attention, stimulate discussion, and eventually motivate other researchers to undertake this type of survey on a more representative sample, using a more robust method which will require considerably larger resources than those that were available to us.

Our study offers a fresh perspective to philosophers of biology and biologists regarding the problem of species. We have indicated that some views heretofore considered to be common knowledge in discussions of the species problem need to be re-examined. Moreover, we hope that the results of this study will prompt biologists to make concerted efforts to arrive at more widely shared answers to some fundamental questions, e.g. what is the unit of evolution, whether species are real entities or not, and what this entails.

The last couple of decades have seen a proliferation of concepts of species proposed. Mayden (1997) identified 22 concepts of species, Wilkins (2002) 26 concepts, in our survey we operated with 29 different concepts of species, and it is possible that the actual number of species concepts in circulation in the field of philosophy of biology is still higher. With the proliferation of species concepts, discussions on the species problem are becoming more complex and at the same time increasingly detached from actual practices and opinions of biologists. This paper is a modest attempt to bring actual views of biologists into discussion.

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Appendix

List of all Universities to which the survey has been sent beyond any reasonable doubt:

1. Adams State University
2. Agnes Scott College
3. Albion College
4. Allegheny College
5. American University
6. Appalachian State University
7. Arizona State University
8. Armstrong Atlantic State University
9. Auburn University
10. Azusa Pacific University
11. Baker University

12. Ball State University
13. Bates College
14. Baylor University
15. Beloit College
16. Benedictine University
17. Berry College
18. Bethany College
19. Bismarck State College
20. Bloomsburg University
21. Boston College
22. Boston University
23. Bowdoin University
24. Bowling Green State University
25. Bradley University
26. Brandeis University
27. Brigham Young University
28. Brown University
29. Bucknell University
30. Buena Vista University
31. Butler University
32. BYU Hawaii
33. California Polytechnic State University San Luis Obispo
34. California State Polytechnic University Pomona
35. California Institute of Technology
36. California State University at Bakersfield
37. California State University at Chico
38. California State University at Dominguez Hills
39. California State University at Fresno
40. California State University at Fullerton
41. California State University at Long Beach
42. California State University at Los Angeles
43. California State University at Northridge
44. California State University at Sacramento
45. California State University at San Bernardino
46. California State University at San Marcos
47. California State University at Stanislaus
48. Californian Lutheran University
49. Carnegie Mellon University
50. Central Connecticut State University
51. Central Michigan University
52. Central Washington University
53. Chadron State College
54. Chalmers University of Technology
55. Chaminade University
56. Chicago State University
57. Clemson University

58. Cleveland State University
59. Coastal Carolina University
60. College of Charleston
61. College of Idaho
62. College of New Jersey
63. College of St. Benedict and St. John's University
64. College of William & Mary at Williamsburg
65. Colorado College
66. Colorado State University
67. Columbia University
68. Connecticut College
69. Cornell University
70. Creighton University
71. Dartmouth college
72. Delaware State University
73. Delta State University
74. DePaul University
75. Drake University
76. Drew University
77. Duke University
78. East Carolina University
79. East Tennessee State university
80. Eastern Arizona College
81. Eastern Connecticut State University
82. Eastern Illinois University
83. Eastern Kentucky University
84. Eastern Michigan University
85. Eastern New Mexico University
86. Eastern Oregon university
87. Eastern Washington University
88. Emory University
89. Fairfield University
90. Farleigh Dickenson University
91. Fayetteville State University
92. Fisk University
93. Florida Institute of Technology
94. Florida State University
95. Fort Hays State University
96. Fort Lewis College
97. Franklin College
98. Furman University
99. George Fox University
100. George Mason University
101. George Washington University
102. Georgetown College
103. Georgia Institute of Technology

104. Georgia Southern University
105. Georgia State University
106. Gonzaga University
107. Goucher College
108. Grambling State University
109. Hampton University
110. Hannover College
111. Harvard University
112. Hawaii Pacific University
113. Henrich-Heine-Universität Düsseldorf
114. Idaho State University
115. Illinois College
116. Illinois Institute of Technology
117. Illinois State University
118. Indiana State University
119. Indiana University Bloomington
120. Indiana University South Bend
121. Iowa State University
122. Jackson State University
123. Jacksonville University
124. James Madison University
125. Johns Hopkins University
126. Kansas State University
127. Keene State College
128. Kent State University
129. Kentucky State University
130. LaGrange College
131. LaSalle University
132. Lawrence University
133. Lehigh University
134. Long Island University
135. Long Island University Brooklyn Campus
136. Louisiana College
137. Louisiana State University Baton Rouge
138. Louisiana State University Shreveport
139. Louisiana Tech University
140. Loyola Marymount University
141. Loyola University Maryland
142. Loyola University New Orleans
143. Marquette University
144. Marshall University in Huntington, West Virginia
145. Mayville State University
146. McDaniel College
147. Mesa State College
148. Metropolitan State University of Denver
149. Miami University of Ohio at Oxford

150. Michigan State University
151. Middle Tennessee State University
152. Middlebury College
153. Midwestern State University
154. Millsaps College
155. Minnesota State University Mankato
156. Minnesota State University Moorhead
157. Mississippi College
158. Mississippi State University
159. Mississippi University for Women
160. Missouri Southern State University
161. Missouri State University
162. Missouri Western State College
163. MIT
164. Monash University
165. Montana State University Bozeman
166. Montana State University Billings
167. Montana Technology
168. Morehead State University
169. Morehouse College
170. Morgan State University
171. Mount Mercy University
172. Murray State University
173. Nebraska Wesleyan University
174. New England College
175. New Jersey Institute of Technology
176. New Mexico Highlands University
177. New Mexico State University
178. New York University
179. North Carolina AT&T State University
180. North Carolina Central University
181. North Carolina State University
182. North Carolina Wesleyan College
183. North Dakota State University
184. Northeastern State University
185. Northeastern University
186. Northern Arizona University
187. Northern Illinois University
188. Northern Kentucky University
189. Northern Michigan University
190. Northern State University
191. Northwest Missouri State University
192. Northwestern Oklahoma State University
193. Northwestern University
194. Norwich University
195. Oglethorpe University

196. Ohio State University
197. Ohio University at Athens
198. Ohio Wesleyan University
199. Oklahoma State University
200. Old Dominion University
201. Oregon State University
202. Ouachita Baptist university
203. Pacific Lutheran University
204. Pacific University
205. Pennsylvania State University
206. Pennsylvania State University in Erie
207. Pepperdine University
208. Plymouth State University
209. Portland State University
210. Princeton University
211. Providence College
212. Purdue University
213. Reed College
214. Regis University
215. Rhode Island College
216. Rice University
217. Rider University
218. Rockhurst University
219. Rocky Mountain College
220. Roger Williams University
221. Rollins College
222. Rutgers University at Camden
223. Rutgers University at New Brunswick
224. Saint Anselm College
225. Saint Mary's University of Minnesota
226. Salisbury University
227. Sam Houston State University
228. Samford University
229. San Diego State University
230. San Francisco State University
231. San Jose State University
232. Santa Clara University
233. Seattle Pacific University
234. Seattle University
235. Seton Hall University
236. South Carolina State University
237. South Dakota State University
238. Southeast Missouri State University
239. Southeastern Louisiana University
240. Southern Connecticut State University
241. Southern Illinois University at Edwardsville

242. Southern Oregon University
243. Southern University at Baton Rouge
244. Southern Utah University
245. Southwestern College
246. Southwestern Oklahoma State University
247. Southwestern University
248. Spalding University
249. Spelman College
250. Stanford University
251. State University of New York at Albany
252. State University of New York at Binghamton
253. State University of New York at Buffalo
254. State University of New York at Oswego
255. State University of New York at Plattsburgh
256. State University of New York at Stony Brook
257. Syracuse University
258. Temple University
259. Tennessee State University
260. Texas A&M University at College Station
261. Texas A&M University at Corpus Christi
262. Texas A&M University at Galveston
263. Texas State University
264. Texas Tech University
265. The University of Rhode Island
266. Transylvania University
267. Truman State University
268. Tufts University
269. Tulane University
270. Tuskegee University
271. University of Alabama at Birmingham
272. University of Alabama at Huntsville
273. University of Alabama at Tuscaloosa
274. University of Alaska at Fairbanks
275. University of Alaska at Juneau
276. University of Arizona
277. University of Arkansas at Monticello
278. University of Arkansas at Fayetteville
279. University of Arkansas at Little Rock
280. University of Bridgeport
281. University of California at Berkeley
282. University of California at Irvine
283. University of California at Los Angeles
284. University of California at Riverside
285. University of California at San Diego
286. University of California at Santa Barbara
287. University of California at Santa Cruz

288. University of Central Arkansas
289. University of Central Florida
290. University of Central Missouri
291. University of Central Oklahoma
292. University of Cincinnati
293. University of Colorado at Boulder
294. University of Colorado at Colorado Springs
295. University of Colorado at Denver
296. University of Connecticut
297. University of Dallas
298. University of Delaware
299. University of Denver
300. University of Detroit Mercy
301. University Of Evansville
302. University of Findlay
303. University of Florida
304. University of Georgia
305. University of Hartford
306. University of Hawaii
307. University of Houston
308. University of Idaho
309. University of Illinois at Chicago
310. University of Illinois at Springfield
311. University of Illinois at Urbana-Champaign
312. University of Indianapolis
313. University of Iowa
314. University of Kansas
315. University of Kentucky at Lexington
316. University of Louisiana at Lafayette
317. University of Louisiana Monroe
318. University of Louisville
319. University of Maine Farmington
320. University of Maine Fort Kent
321. University of Maryland at Baltimore County
322. University of Maryland at College Park
323. University of Massachusetts at Amherst
324. University of Massachusetts at Boston
325. University of Massachusetts at Dartmouth College
326. University of Massachusetts at Lowell
327. University of Memphis
328. University of Miami
329. University of Michigan at Ann Arbor
330. University of Michigan at Dearborn
331. University of Michigan at Flint
332. University of Minnesota at Morris
333. University of Minnesota Duluth

334. University of Minnesota Twin Cities
335. University of Mississippi
336. University of Missouri at Columbia
337. University of Missouri at Rolla
338. University of Missouri at St. Louis
339. University of Montana
340. University of Nebraska – Lincoln
341. University of Nebraska at Omaha
342. University of Nebraska Kearney
343. University of Nevada Las Vegas
344. University of Nevada Reno
345. University of New England
346. University of New Hampshire
347. University of New Haven
348. University of New Mexico
349. University of New Orleans
350. University of North Alabama
351. University of North Carolina at Asheville
352. University of North Carolina at Chapel Hill
353. University of North Carolina at Charlotte
354. University of North Carolina at Greensboro
355. University of North Carolina at Pembroke
356. University of North Carolina at Wilmington
357. University of North Dakota
358. University of North Texas
359. University of Northern Colorado
360. University of Northern Iowa
361. University of Notre Dame
362. University of Oklahoma
363. University of Oregon
364. University of Pennsylvania
365. University of Pittsburgh
366. University of Pittsburgh at Johnstown
367. University of Portland
368. University of Richmond
369. University of Rijeka
370. University of Rochester
371. University of San Diego
372. University of San Francisco
373. University of Scranton
374. University of South Alabama
375. University of South Carolina at Aiken
376. University of South Carolina at Columbia
377. University of South Carolina at Spartanburg
378. University of South Dakota
379. University of South Florida

380. University of Southern California
381. University of Southern Indiana
382. University of Southern Maine
383. University of Southern Mississippi at Hattiesburg
384. University of St. Thomas
385. University of Tampa
386. University of Tennessee at Chattanooga
387. University of Tennessee at Knoxville
388. University of Tennessee at Martin
389. University of Texas at Arlington
390. University of Texas at Austin
391. University of Texas at Dallas
392. University of Texas at El Paso
393. University of Toledo
394. University of Tulsa
395. University of Utah
396. University of Vermont
397. University of Virginia
398. University of Washington
399. University of West Alabama
400. University of West Florida
401. University of West Georgia
402. University of Wisconsin at Eau Claire
403. University of Wisconsin at Green Bay
404. University of Wisconsin at LaCrosse
405. University of Wisconsin at Madison
406. University of Wisconsin at Milwaukee
407. University of Wisconsin at Oshkosh
408. University of Wisconsin at Parkside
409. University of Wisconsin at River Falls
410. University of Wisconsin at Superior
411. University of Wyoming
412. Utah State University
413. Utah Valley State College
414. Valdosta State University
415. Vanderbilt University
416. Villanova University
417. Virginia State University
418. Virginia Tech
419. Wake Forest University
420. Washington State University
421. Washington University in St. Louis
422. Wayne State University
423. Weber State University
424. Wesley College
425. West Liberty University

426. West Texas A&M University
427. West Virginia University
428. Western Carolina University
429. Western Connecticut State University
430. Western Illinois University
431. Western Kentucky University
432. Western Michigan University
433. Western New England College
434. Western New Mexico University
435. Western Oregon University
436. Western State College of Colorado
437. Western Washington University
438. Wheaton College
439. Wichita State University
440. Wingate University
441. Winona State University
442. Xavier University
443. Xavier University of Louisiana
444. Yale University
445. York College
446. Youngstown State University

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