



Effects and perception of marine introduced species by stakeholders in the Wadden Sea—an exploratory approach

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Abstract

As a result of globalization of markets and increasing marine traffic, more than 130 introduced species have so far been recorded in the Wadden Sea. This unique coastal area constitutes an ecosystem of global importance and is recognized by UNESCO as a Natural World Heritage site. Efforts are made to monitor introduced species and to study their ecological effects on native species and biodiversity, ecosystem processes, and functioning. Social aspects that relate introduced species specifically to people and human society, however, are less studied. To explore this rather new field of research, qualitative interviews were conducted with stakeholders of the Wadden Sea, asking (1) How do introduced species affect people's lives and (2) How do people perceive introduced species? The interviews were evaluated with a qualitative content analysis. As one first result of this exploratory study it turned out that immaterial aspects of the Wadden Sea, such as recreational potential and cultural identity, appear to be largely affected by introduced species. Moreover, the mere fact of change was mostly regarded with skepticism or aversion, regardless of actual effects. Based on the stakeholder interviews, a conceptual framework with the factors identified as influencing perception was developed. It is suggested that a better understanding of the social component is essential for an integrated management and sustainable solutions.

Keywords IPBES · Interviews · Neobiota · Non-material · Social

Introduction

As a natural part of evolutionary processes species have regularly expanded their dispersal areas—in the marine context, for example, by rafting on floating items such as macroalgae or volcanic pumice (Thiel and Gutow 2005; BIOCONSULT 2015; Lackschewitz et al. 2015). However, dispersal

possibilities of species have grown due to human activities and increased supply of anthropogenic floating material, resulting in geographical barriers no longer hindering a spread to other remote regions, water bodies, and environments (Thiel and Gutow 2005; Kowarik and Rabitsch 2010). Increased globalization of markets and shipping traffic have notably accelerated the translocation of marine organisms in the last decades, even into the shallow Wadden Sea in the south-eastern North Sea, which represents the largest contiguous soft-bottom coastal ecosystem in the world. In the Dutch part of the Wadden Sea alone, the number of known introduced species rose from 50 in 2009 to 82 new residents in 2014 (Gittenberger et al. 2015; Büttger et al. 2017). Not quite as drastic, but similar in the trend is the development in the German and Danish Wadden Sea. While in the German part nine new benthic organisms were recorded between 2009 and 2015 as well as between 2017 and 2020 (Büttger et al. 2022), the rate of first records in Denmark increased from a maximum of four per decade (from 1900 to 1989) to up to 15 every ten years since 1990 (Büttger et al. 2017).

With its high rate of biological production and variety of transitional habitats, such as salt marshes, brackish estuaries,

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mudflats and sandbanks, bays and reefs, the Wadden Sea sustains a multitude of often highly specialized biota (Reise 1985; Gätje and Reise 1998; Common Wadden Sea Secretariat 2010a, 2017, 2021; Gittenberger et al. 2015). However, the introduction and establishment of new species change the dynamics of the ecosystem and the interactions between species and with the abiotic environment, which can induce shifts and changes to biodiversity in the Wadden Sea but also in other coastal systems (Occhipinti-Ambrogi 2007; Buschbaum and Lackschewitz 2018; Jaureguiberry et al. 2022; Reise et al. 2023). Changes in ecological processes and structures, such as in the food web, species' composition, or environmental conditions, might in the long term have direct or indirect consequences for the human being, for example, by altering the provision of nature's contributions to people (Costanza et al. 2017; Pascual et al. 2017; Brondízio et al. 2019; Howard 2019). Currently, the number of inhabitants living in direct proximity to the Wadden Sea coast amounts to approximately 3.7 million plus about 10 million tourists and other linked people, whose well-being might be affected thereby (Common Wadden Sea Secretariat 2017; Sijtsma et al. 2019). As humans are therefore not only the catalyst for this change but also concerned with the outcome on manifold levels, the global phenomenon of species introductions requires coupled social-ecological research approaches and the integration of social questions (Kabat et al. 2012; Bennett et al. 2017; Markus et al.

2018; Howard 2019; Shackleton et al. 2019a, b; WG-AS and Gittenberger 2019; McKinley et al. 2020). As a starting point for this, Shackleton et al. (2019a) propose four main spheres in which humans are intricately linked with species introductions (Fig. 1). However, rather than representing independent research areas, they are interconnected and influenced by one another. While according to Shackleton et al. (2019a) a solid understanding of all four aforementioned areas is necessary for an effective management of species' introductions, in this paper, the second (*humans being affected*) and the third research area (*humans perceiving*) will be examined in relation to the Wadden Sea Region (see orange box in Fig. 1). Correspondingly, two research questions were formulated.

1. Effects: How do marine introduced species in the Wadden Sea affect people's lives? In which respect do people feel affected?
2. Perception: How do people perceive marine introduced species and species introductions in the Wadden Sea? How is their perception shaped?

Particularly in the marine context, both mentioned research areas are not yet very well explored. Studies, such as the pan-European review of Katsanevakis et al. (2014), a large-scale analysis of effects of marine neobiota embedded in the "ecosystem service" framework, are rare and mostly focused either

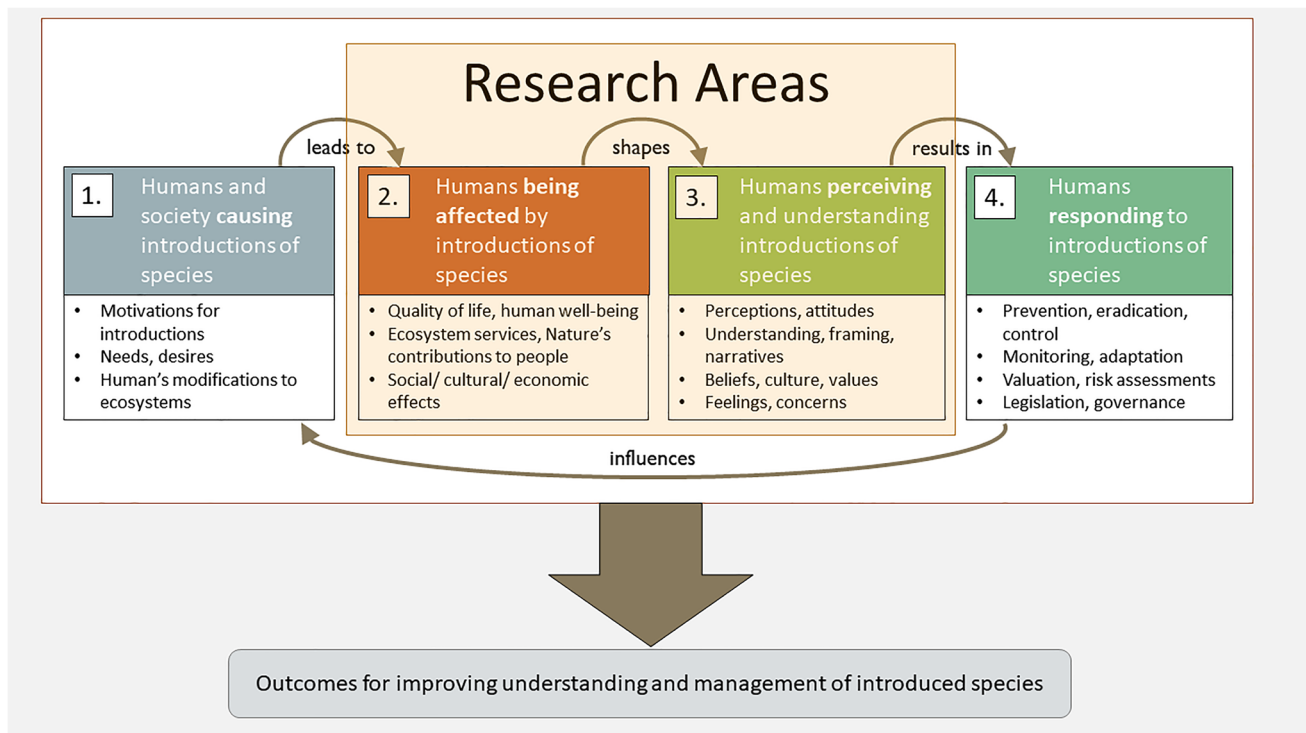


Fig. 1 Four Research areas combining social and ecological questions of species introductions. Modified from Shackleton et al. (2019a), Fig. 2. The orange box indicates the two areas that are addressed in this paper

on one particular stakeholder group or on a type of effect (Estévez et al. 2015; Vaz et al. 2017; Townsend et al. 2018; Howard 2019). The question of perception of introduced species to understand how this shapes people's responses to them has long been neglected in research and management but has seen an uptake in recent years (Verbrugge et al. 2013; Kueffer and Kull 2017, Kapitza et al. 2019, Shackleton et al. 2019b and references therein; Vaz et al. 2021).

As is suggested by Fig. 1, a thorough understanding of these mentioned questions involving human relations to neobiota is necessary with regard to recognition of different interests and attitudes of stakeholders, identification of reasons for opposition and acceptance of measures, resolving conflicts and eventually for executing effective, comprehensive, and collaborative solutions (Estévez et al. 2015; Kapitza et al. 2019; Razzaque et al. 2019; Shackleton et al. 2019a, b; Vaz et al. 2021). Different notions and understandings of knowledge, of nature and of its relations with humans must therefore be incorporated (Brondízio et al. 2019; Shackleton et al. 2019a, see also Fig. 1; Vaz et al. 2021). Hence, we decided for a framework including diverse stakeholder groups. The Wadden Sea was particularly of interest for this study for three reasons. Firstly, a number of factors such as large economic activities and improved monitoring and detection capacities increase the number of neobiota respectively knowledge on them. Secondly, and this plays into the first reason, the Wadden Sea Region is home and resort to millions of people, which makes it inevitably a vivid example of human interactions with the environment in coastal areas. Thirdly, its conservation is jointly managed on an international level following the Trilateral Wadden Sea cooperation (Common Wadden Sea Secretariat 2010a, b; WG-AS and Gittenberger 2019), which makes efforts for inter- and transdisciplinary collaboration on top of trilateral understanding extraordinarily interesting.

Material and methods

To uncover how the stakeholders in the Wadden Sea are affected—or to be more precise, how they feel affected—by neobiota, and moreover, how they perceive and feel towards introductions of marine species in the Wadden Sea, problem-centered interviews (PCI) were conducted. A PCI is a qualitative research method that allows to collect non-standardized in-depth data such as experiences, feelings, or attitudes, which are hardly captured with quantitative and standardized research methods (Döringer 2020; Froschauer and Lueger 2020). Characteristic of the PCI is a self-developed guideline consisting of interview questions (or “stimuli,” see Kruse 2015), which have been prepared beforehand, based on prior knowledge and assumptions (Table 1) (Witzel and Reiter 2012; Przyborski and Wohlrab-Sahr 2013; Kruse 2015;

Loosen 2016). By providing a possible systematic structure for leading through the questioning process (Przyborski and Wohlrab-Sahr 2013), the guideline sets the thematic frame for the problem that is to be explored (Witzel and Reiter 2012; Kruse 2015; Loosen 2016; Froschauer and Lueger 2020). Concurrently, this design is intended to be flexible enough to allow for follow-up questions, language clarifications, or other necessary adjustments for the respondents to narrate freely in the context of the questions (Witzel and Reiter 2012; Döringer 2020). Within the thematic frame, the order of the questions as well as the questions themselves can and should be adapted to the flow of the conversation by aligning with what the interviewee considers relevant (Przyborski and Wohlrab-Sahr 2013; Kruse 2015). The adaptation and implementation of newly gained insights during the process into the research design and thus the constant re-evaluation of the research are common practice in qualitative research (Przyborski and Wohlrab-Sahr 2013). This openness of the approach towards the process itself as well as to results in combination with the semi-structured framework enables to bridge the gap between “two seemingly contradictory sources of knowledge, as [the PCI] gives equal right to the previously accumulated theoretical and empirical knowledge of the researcher and to the individual knowledge and personal experiences of the respondent” (Döringer 2020: 268). Hence, to exploit the full potential of this tension between inductive and deductive approaches, PCI were chosen as suitable for both research questions (see also Kruse 2015).

In the research design of this paper, 13 leading questions (and two optional ones) were selected with the two major sections being analogous to the two formulated research questions on effects and perception (3.–6. respectively 7.–12. In Table 1).

As the (unattainable) aim of the interviews was to depict the entire spectrum of social effects, (i.e., in which respect people feel affected), of experiences, perceptions, and understandings, the interviewees were to reflect this heterogeneity in their profession or activities related to neobiota in the Wadden Sea. The sectors specifically engaged with marine neobiota of the Wadden Sea were derived from related literature (for example, Katsanevakis et al. 2014; Buschbaum et al. 2012; Lackschewitz et al. 2015; Gittenberger et al. 2015; Bos et al. 2016; Gittenberger 2016; Gittenberger et al. 2017; Rabitsch and Nehring 2017; Reise et al. 2023), which provided initial indications of positively and negatively affected professions and sectors (Table 2). For the recruitment, the homepage and published list of members of the Wadden Sea Forum e.V., an independent platform of the Trilateral Cooperation to represent the multitude of interest groups in the Wadden Sea, served as a starting point (Wadden Sea Forum e.V. 2021). The sample was complemented by snowball sampling, in which further suitable interviewees or involved sectors of activity were identified by already

Table 1 Interview guideline consisting of two major sections of interview questions. The colored questions correspond to the proposed research areas of Fig. 1

Guideline		
1.	Introductory questions	How would you describe your connection to the Wadden Sea?
2.		Which terms do you usually use to refer to introduced species and why?
3.	Research question 1: Effects (corresponding to Research area 2 in Fig. 1)	In what kind of situations do you encounter marine introduced species? What did you observe and experience there?
4.		How do introduced species play a role in your professional context?
5.		To what extent do they affect your life, your personal actions or your field of work?
6.		What kind of positive or negative effects in terms of neobiota do you notice from other people in the Wadden Sea Region?
7.	Research question 2: Perception (corresponding to Research area 3 in Fig. 1)	What thoughts, pictures and associations come up when you think about introduced species?
8.		How would you describe your basic feeling concerning introduced species? How did you develop your attitude, and has it changed over time?
9.		What worries, annoys or saddens you regarding introduced species? What influences your attitude positively? What do you see as an opportunity?
10.		How do you perceive other residents in the Wadden Sea Region to view this topic? What reactions do you notice from others and what do you think are possible reasons for them?
11.		What factors do you think influence people's perception of introduced species? What influences you personally?
12.		In how far has your perception of the Wadden Sea changed due to marine introduced species?
13.	Optional	How do you perceive the public discourse and communication about introduced species?
14.		How do you assess people's possibilities for exerting influence on the issue of introduced species? How should we approach this topic?
15.	Closing question	Lastly, is there anything else you would like to share, something that wasn't asked in the interview or something you still would like to say?

interviewed respondents (for example “food security,” see Table 2) (Przyborski and Wohlrab-Sahr 2013). The research design was narrowed down to the German part of the Wadden Sea Region and to marine neobiota, excluding terrestrial species. All selected interviewees had a personal connection to the Wadden Sea, not only in terms of profession, but also regarding their place of residence or preferred recreation area. As the field of activity or association with a stakeholder group was considered here the main key to the interviewees' individual perspective, demographic factors apart from gender were no criteria in the selection of the interviewees. While we argue that all groups of people feeling connected to the Wadden Sea should be included in research and subsequent decision-making processes, the basic knowledge and ability to distinguish local species from neobiota was considered essential for this research design. Therefore, it was decided to exclude tourists, who would demand different research methods other than PCI. Overall, ten interviews were conducted, covering eight groups of interest (Table 2).

Data collection took place in June until August 2021. The interviews were held in German and carried out via telephone or videoconference (due to the corona pandemic).

The final audio length of each interview ranged from 23 min to almost an hour.

After completion of the interviews, all postprocessing was performed in the software program MAXQDA, including the transcription of the recorded audio. For this purpose, 24 transcription rules were established, which were based on the transcription system developed by Bohnsack (2021). Subsequently, the transcripts were systematically coded, following the structured process of a qualitative content analysis of Kuckartz and Rädiker (2022). Elementary in a qualitative content analysis is the development of a dynamic category system by assigning codes to text passages to allow an interpretive exploration of the documents (Kuckartz and Rädiker 2022).

The coding process differed for the two research questions:

- 1 An effect was defined here as a discernible, measurable, or perceived change to the well-being of a person. The underlying premise here is that neobiota only affect people's quality of life, positively or negatively, if people perceive them to do so (compare Howard 2019). For this part of the analysis, it was drawn upon the con-

Table 2 Sample. Some respondents held multiple functions and were classified to more than one sector of activity

Sector of activity	Number of respondents
Tourism, marketing	2
Recreation, education	3
Fishery, aquaculture	2
Food safety	1
Port industry, maritime shipping	1
Science	2
Nature conservation	1
Landscape management	2

ceptual framework of the *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services* (IPBES) and their draft of a *Good quality of life* (GQL). IPBES' concept of a *Good quality of life* is part of a tripartite structure, furthermore encompassing *Nature* and the interlinking *Nature's Contributions to People*, which build upon the ecosystem services framework of the Millennium Ecosystem Assessment in 2005 (Brondízio et al. 2019). What someone perceives as constituting a good quality of life depends on factors like the cultural background, underlying social norms and current circumstances (Brondízio et al. 2019). The concept of GQL is an attempt to capture those different visions and sub-concepts like “welfare” or “human well-being” into 15 unifying categories, broadly divided into a material and a non-material dimension, encompassing six and nine indicators respectively (Brondízio et al. 2019; Shin et al. 2019; for definitions, see electronic supplement). The material benefits people experience are of instrumental value and fulfill basic human needs. They include access to resources, such as food, water, shelter, or energy (Brauman et al. 2019; Brondízio et al. 2019; Shin et al. 2019). As opposed to non-material categories, they are gained by direct use, whereas non-material contributions to GQL are obtained by interaction with and relating to, in this case, the Wadden Sea (Brauman et al. 2019; García Rodrigues et al. 2022). Non-material indicators are of very subjective nature and encompass individual aspirations, capabilities or relationships (Brondízio et al. 2019). With this concept, IPBES—an institution at the interface of science and policy with regards to biodiversity and its interrelations to humans—seeks to reconcile competing conceptualizations of human-nature relations and different forms of knowledge (Borie and Hulme 2015). By situating this paper's research in this inclusively designed framework, it was aspired to contribute to the manifestation of a broaden scientific discourse

(Díaz et al. 2018; Brondízio et al. 2019). Furthermore, by using the 15 related indicators as a category grid for analyzing reported effects on the quality of life of the respondents, the relevance of material and non-material indicators for species' introductions could be examined in more detail.

- The second research question focuses on perception, which can be regarded as an umbrella term (cf. Shackleton et al. 2019b). According to Kueffer and Kull (2017), it “refers to the ways in which humans filter, organise and interpret information from the outside world” (p. 312; see also Schermerhorn et al. 2000). As such, perception is dynamic and contextual, i.e., it can vary according to time, place, and other situational factors (Kueffer and Kull 2017). Whereas the coding analysis for the first research was, as described above, pre-structured and deductive, the exploration of the multiple factors that influence the lens through which individuals perceive was approached inductively. This implies that, as opposed to deductive approaches, theories are derived from the data at hand and that no pre-determined pattern, in this case in the form of existing categories, is underpinned (Kuckartz and Rädiker 2022).

For the purpose of evaluation, visual tools, matrices, and other tools available in MAXQDA were used, which made it possible to identify relationships between categories and subcodes.

In this research design, verbal data were collected, the analysis of which must always take into account the context of the statements, interpersonal communication rules, and the like in order to ensure valid and comprehensible interpretations (Przyborski and Wohlrab-Sahr 2013; Froschauer and Lueger 2020). Consequently, the classical quality criteria of quantitative methods such as validity and objectivity cannot be transferred to qualitative research in the same form (Przyborski and Wohlrab-Sahr 2013; Kuckartz and Rädiker 2022). As selection and abstraction are (as generally in research) unavoidable, the goal of this study was set to so-called intersubjectivity instead of objectivity (Lamnek and Krell 2016). Intersubjectivity is given when there is a general consensus in society on the coherence and comprehensibility of interpretations (Lamnek and Krell 2016). Scientificity of this “methodically controlled external understanding,” as Przyborski and Wohlrab-Sahr call it (2013: 11), was ensured by applying quality criteria, such as process documentation and rule-governedness, as recommended by Mayring (quoted from Lamnek and Krell 2016: 145). A questionnaire from Kuckartz and Rädiker (2022: 237f.) was furthermore used as a guidance to question whether the collected data material is really suitable to discuss the research question.

Throughout the interviews and the next chapters of this paper the term introduced species is used synonymously with neobiota and refers to species introduced by human activities such as shipping and aquaculture (cf. EU Regulation No 1143/2014, Article 3).

Results

The most relevant findings of the analysis of the interviews will be presented in the following, some of which will be underpinned with selected quotes of the respondents. We first address the research question on how marine introduced species in the Wadden Sea affect well-being. This is based on the 15 categories of GQL developed by IPBES. The second research question on people's perception of neobiota and the formation of their perception is dealt with in the section thereafter.

Effects on people's quality of life

In the interviews, respondents were asked for changes and effects that they perceived to have happened due to the introduction of species into the Wadden Sea, either to them personally or to others. All statements were allocated to the 15 categories of GQL (Brondizio et al. 2019). Table 3 shows the categories that are perceived to have been subject to change, either in the form of an improvement or of a decline of the life quality, and further reflects the frequency of mentions in the interviews.

Two findings are particularly noteworthy. Firstly, positive effects were less often identified than detriments. Secondly, the share of non-material indicators slightly predominates.

Distribution of negative and positive effects across categories

Three categories were especially dominated by detriments: *Health*, *Freedom of choice and action*, and *Sense of cultural identity*. As for health, the introduction of a new spectrum of bacteria, viruses, or pathogens was stated to not only have consequences for marine organisms, but to possibly affect people by the consumption of seafood. Therefore, concern was expressed about the collection and consumption of introduced Pacific oysters *Magallana gigas* (Thunberg, 1793) on a private basis in the Wadden Sea, as these need to be controlled first for food safety. This species was introduced for aquaculture purposes on a large scale in the 1980s and nowadays occurs in the entire Wadden Sea with densities up to 3000 individuals m^{-2} (Reise et al. 2017). Other negative health effects include cuts due to sharp shells of Pacific oysters. This has become particularly dangerous in recreation activities such as surfing, mudflat hiking, or beach activities. The Pacific oyster was also highly related to detriments in the fishery sector, as they pose the risk of damaged fishing nets. Hence, changes to established fishery and harvesting methods became inevitable, which affects, among others, the other two immaterial categories *Freedom of choice and action* and *Sense of cultural identity*. Notwithstanding alternative culturing methods, the economic viability has largely decreased, and frustration is reported to have spread among the fishermen.

In contrast, especially aquaculture was also associated with harnessing new earning opportunities and finding economic utility in the newly arrived biota as a new and varied food source, such as the American razor clam *Ensis leei* (M. Huber, 2015) or the Pacific oyster. Interesting new marketing possibilities of introduced species would be an asset for tourism and recreation likewise.

Table 3 Number of statements by the respondents allocated to the respective categories of a good quality of life that are affected by marine introduced species in the Wadden Sea, broken down by benefits and detriments. Categories of a good quality of life that were not coded in the interviews are not displayed

Categories of a good quality of life (IPBES)		Benefit	Detriment	SUM
Material dimension	Food security	10	4	14
	Livelihood and income security	5	7	12
	Health	0	11	11
	SUM	15	22	37
Non-material dimension	Good social relationships	1	0	1
	Sense of cultural identity	3	9	12
	Personal and physical security	0	4	4
	Freedom of choice and action	1	9	10
	Access to knowledge and education	8	0	8
	Access to recreation and leisure	6	5	11
	Enjoyment of natural beauty	2	2	4
	SUM	21	29	50
Total SUM	36	51	87	

Distribution of non-material and material categories

Overall, the qualitative analysis revealed a higher coding frequency of the non-material categories of a good life quality than of the material categories. Examples include the abovementioned categories of *Sense of cultural identity* and *Freedom of choice and action*, both of which were frequently linked to changes in the routine of the respondents, for which adaptation is now required. Recreation is similarly affected. For example, reefs of introduced Pacific oysters were perceived to present a hindrance for recreation vessels due to routes becoming impassable or former anchorage areas no longer being approachable. In the worst case, damages to boats and ships can also be accompanied by a reduction of the non-material indicator *Personal and physical security*, especially on busy sea lanes. In this context, experiences of suddenly damaged machinery due to fouling communities were mentioned, resulting in an impaired maneuverability. Effects are apparently not only perceived in a private context but also on a professional level, as for example flood gates of the Waterways and Shipping Office are not running properly anymore and cleaning costs, e.g., of pipes have increased due to fouling. Strikingly, the majority of codes for these categories was associated with negative effects.

However, with the help of double-coding of segments that matched several categories, links between the material and the non-material dimension could be analyzed. One example concerns the material *Food security* and the non-material *Access to recreation and leisure*:

R: Well, in the sea, I always tell my boys, collect what you can get out of it. Because that's funny. I mean, everything that you can eat, collect it. That way you will teach the people a different kind of eating.

The statement indicates that the collection of one's own food (*Food security*) in the Wadden Sea is a joyful activity (*Access to recreation and leisure*) and may furthermore even serve as an inspiration for a diversified cuisine by conveying a different approach to food. It can thus be construed as also having an educational value and could possibly be associated with the non-material *Access to knowledge and education*.

Perception of introduced species

We further explored people's perception of neobiota and their introductions in the Wadden Sea. This was analyzed in two steps. It was analyzed on the one hand, what people think and feel about marine introduced species, and on the other hand, by which factors human perception of these species is influenced. Factors are defined here as influencing

variables that emerged from the coding analysis. Regarding the first aspect two observations could be made. Firstly, the introduction of species was discussed and reflected upon in the interviews in a very differentiated way. Apart from two respondents, most considered both positive and negative aspects and effects of neobiota, but with a general tendency towards being critical of introductions. However, secondly, their perception of particular species is dynamic over time and place and differs depending on the species. The Chinese mitten crab *Eriocheir sinensis* (Milne Edwards, 1853) for example was met with aversion, whereas the introduced American razor clam *E. leei* was seen more favorably. Furthermore, attitudes can change over time, when the influencing factors that led to one's perception have changed. The following respondent for example stated to be viewing things more optimistically after concerns of species extinctions proved unfounded over time. This answer was given in the context of the interaction between native blue mussels and introduced Pacific oysters.

R: Now that I see that blue mussels are able to prevail after all, I'm a bit more optimistic than I was a few years ago, when I thought, well, that's it now for the native mussel, it's gone now. So there ... as I see it, nature apparently sorts it out in the end.

This leads to the second part, in which the various factors that shape people's individual perception of this topic were explored. Broadly, 26 factors including subfactors were found, which were assigned to five superordinate categories of different types of factors (*Personal Involvement, Individual-related factors, Situational factors & circumstances, Species-related factors, Outer factors*, see Table 4). A document with all the definitions and coding criteria underlying the coded factors is attached in the electronic supplement.

Furthermore, two mechanisms of action could be identified for the influencing factors: while some factors raise people's awareness of neobiota, i.e., enable them to notice and recognize species as introduced, others are directly shaping people's perception and attitude to neobiota. Awareness-raising factors can therefore be regarded as the necessary preliminary stage to the subsequent factors determining one's perception. The factor *Knowledge* proved difficult to classify. On the one hand, it was judged to be necessary for developing awareness in the first place, e.g., to learn about the fact that there are species being introduced. On the other hand, knowledge is also an elementary component for shaping one's perception and opinion on neobiota. Context-specific definitions of *Knowledge* are given further on in the text.

All subsequent explanations of the results are based on Fig. 2, which was created to visualize the relationships between the five factor categories of Table 4 and their mechanisms of action. The explanation will start with the category of awareness-raising factors called *Personal*

Involvement (colored blue) and then continues with the other four categories of perception-shaping factors in order of Table 4, i.e., as follows: *Individual-related factors* (orange), *Situational factors and circumstances* (grey), *Species-related factors* (green), and *Outer factors* (yellow).

Personal involvement (awareness-raising factors)

The first category *Personal involvement* encompasses all the awareness-raising factors (marked blue in Fig. 2). As implied by the name, it describes the extent of involvement of a perceiving individual with the subject neobiota. Without the fulfillment of minimum one factor of this category, a person is not likely to notice an introduced species, let alone to evaluate it. *Sense of place*, for example, one of the corresponding factors, is a prerequisite for being concerned and interested in developments of the area. The relevance of *Contact & visibility* can be exemplified by the number of codes for introduced species. Although the focus of the interviews was supposed to be on marine introduced species, a total of 33 mentions of terrestrial neobiota was recorded in contrast to 83 codes for marine neobiota. They appear to be more dominant in

people's consciousness than marine species, which was attributed by the respondents to less visibility of marine species and fewer points of contact with the lives of people. *Knowledge*, in this context defined as the explicit knowledge of the existence of introduced species and the ability to recognize and distinguish introduced species from others, is important to become aware of introduced species in one's surroundings.

After being aware of an introduced species—metaphorically speaking, after the introduced species (marked in green) has entered the sphere of *Personal Involvement* (as visualized in Fig. 2)—the other four categories of perception-forming factors come into play: *Individual-related*, *Species-related*, *Situational*, and *Outer factors*.

Individual-related factors

The set of *Individual-related factors* (marked orange in Fig. 2) is composed of *Demographic factors* such as age or occupation, of *Knowledge*, of *Inner factors*, and of *Beliefs & understanding*. They are voiced by questions such as “What personal features do I bring, and how do they influence my approach to introduced species?” *Inner factors* include two

Table 4 Overview of mechanisms of action, categories, factors, and subfactors influencing perception of introduced species, as identified from a coding analysis of the interviews. All five categories are colored in accordance with the colors used in Fig. 2

Mechanism	Category	Factor	Subfactor
Awareness-raising	Personal involvement	Influence on personal life	
		Contact & visibility	
		Sensory experience	
		Sense of place	
		Knowledge	
Perception-shaping	Individual-related factors	Beliefs & understanding	Human intervention
			Change, novelty & willingness to adapt
			Nature & ecosystems
			Aesthetics
		Time, the world & human beings in relation to it	
		Inner factors	Character traits
	Scientific interest & curiosity		
	Demographic factors	Age	
		Occupation	
	Situational factors & circumstances	Direction of effects	Utility – useful/ useless
			Impact – harmful/ harmless
		Ability to exert influence	
	Ability to adapt		
	Species-related factors	Ecological effects	
		Residence time	
Traits & properties		Rarity	
		Mass occurrence	
Outer factors	Communication: Content & language	Media	
		Other people	
		Science	

further sub-categories, one of which was broadly labeled *Character traits* (see Table 4), meant to include for example the ability for critical thinking and observation skills. Secondly, a scientific interest for the change of natural processes as a result of neobiota as well as curiosity were mentioned by three respondents. The coded phrases of the mentioned subfactors were related to fostering knowledge and to a more open-minded attitude towards neobiota. *Knowledge* itself can be assumed to be a highly influencing factor, as it was mentioned by several respondents to form an opinion and enable people to differentiate and consider different aspects. In this context, a broader notion of *Knowledge* is meant, which encompasses the explicit knowledge of introduction processes and causes as well as ecological knowledge of specific introduced species. This allows oneself to consider

different aspects related to introduced species and to recognize interrelations and evaluate past experiences with them.

The interviews also shed light on the various beliefs (conceptions) of the interviewees. As the factor of *Beliefs & understanding* was coded 50 times, which is by far more than any other factor, it can be cautiously concluded that it is particularly influencing people’s perception. Some subfactors are briefly discussed, starting with the most salient of the interviews according to the number of codes: *Change, novelty & willingness to adapt*. It was reflected by the respondents that in the majority of cases, change is negatively perceived at first. For example, one respondent mentioned:

R: Therefore, neobiota - or anything that is new - is always threatening in some way. And I don’t think that

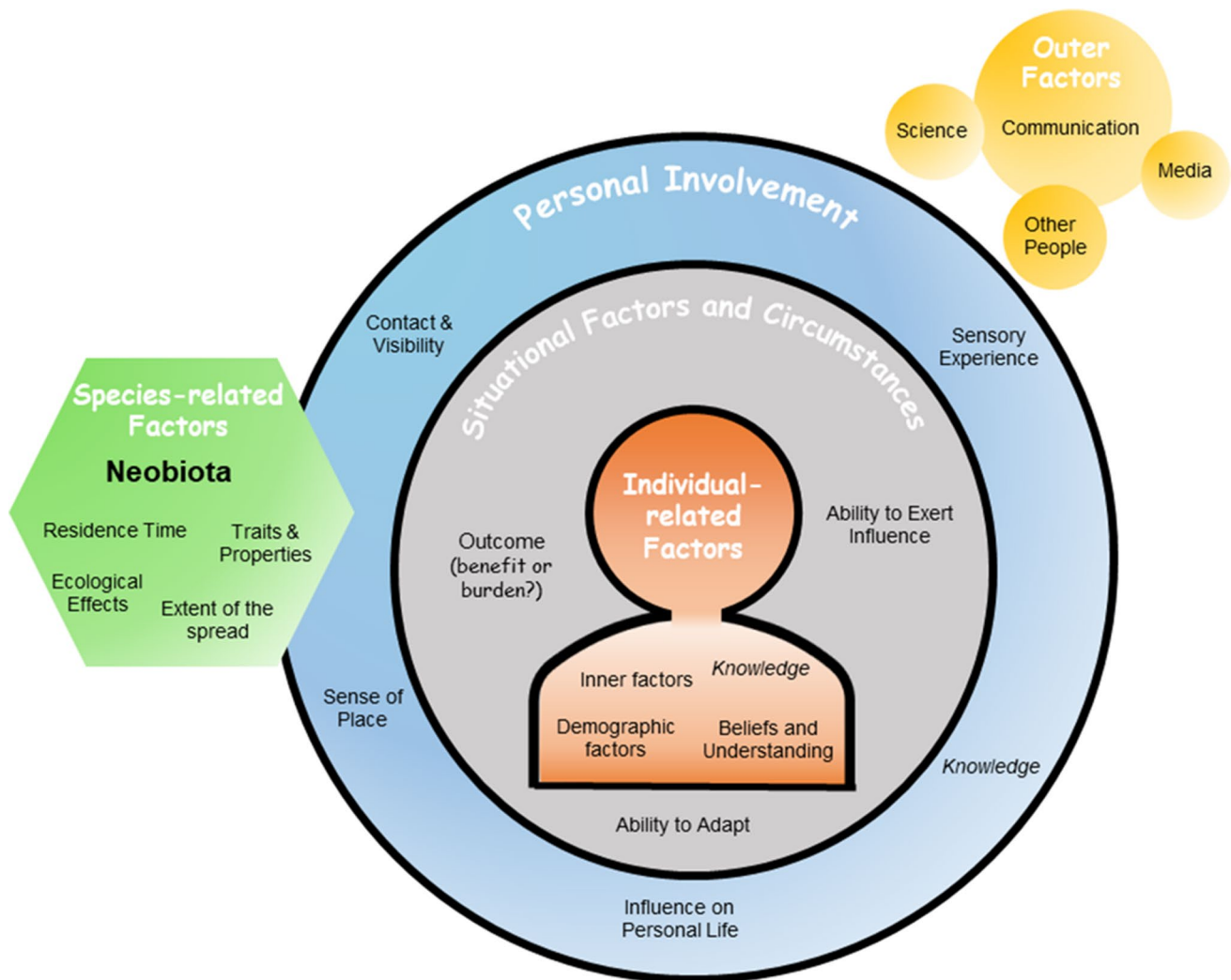


Fig. 2 Conceptual framework of factors influencing perception of neobiota: illustration of five categories of factors determining perception of neobiota (marked in white font and each one colored differently but corresponding to the colors used in Table 4 (orange, grey,

blue, green and yellow). They are arranged according to their relation to the perceiving individual (depicted in orange). Knowledge was listed twice, as it fits two categories (personal involvement and individual-related factors). More detailed information is given in the text

the cause for that is the fact that any living creatures or animals pose a danger, but rather the change itself.

As indicated by this statement, the reasons for the rejection stem from the fact that something is changing, the form of change is not necessarily relevant at first. Several statements further suggested that the trigger of change is a pivotal evaluation criterion for people, which leads to the subfactor *Human intervention*. As such, species that migrate through natural distribution processes were seen more favorably, whereas humans as the vector of change were seen critical (compare also Humair et al. 2014 and references therein). It was even one of merely two factors in total that were consistently assessed as negative across all assigned codes. This finding is in line with the general negative perception of ecological changes in the Wadden Sea due to neobiota, as opposed to the natural changeability of the Wadden Sea, which was generally positively associated and highlighted as a highly cherished characteristic by many.

Different beliefs pertaining to *Nature and ecosystems* also influenced perceptions about introduced species. An understanding of the Wadden Sea's ecosystem as fragile sustained worry and concern about neobiota. A change in the understanding of communities towards viewing them as more resilient may however evoke a more relaxed view, as mentioned by this stakeholder:

R: Well in the past I think I thought more that it is totally - and always - dangerous when a foreign species immigrates and spreads, that everything will be thrown off balance and so on, and now we – and me too – we have a different understanding of communities, that they are often very flexible and very resilient. Well not always, but that it is not necessarily a disaster or a great change when a new species immigrates.

Apart from this, seeing processes and changes in the Wadden Sea in the context of a long time span, i.e., surpassing a human's lifespan, may add to a more balanced view.

Situational factors and circumstances

The category situational factors and circumstances (marked grey in Fig. 2) includes three factors that are outside of the individual's sphere of influence: *Direction of effects*, *Ability to exert influence*, and *Ability to adapt*. The direction of an effect, i.e., whether it is regarded as useful or harmful, was found to be highly influencing. An effect does not necessarily have to be linked directly to oneself, a negative or positive view can also derive, e.g., from hearsay or otherwise acquired knowledge. This indicates how effects, which was dealt with in the first part of the study, are linked to perception.

The second factor of the *Ability to exert influence* is related to introductions in general and less to a specific species. In this framework, this denominates the perceived ability or inability to influence the phenomenon of species introductions, for example, to prevent them from the outset. In the interviews, it was found that both, the assumption that one cannot do anything about introductions as well as the certainty that all options of management are exhausted, can be somewhat comforting to people. The realization, that neobiota have to be accepted as an unpreventable and unchangeable part of the Wadden Sea, only allows the conclusion that one must adapt to these new circumstances. Hence, acceptance and adaptation create a more balanced view and add to people's quality of life (Di Fabio and Gori 2016). However, and this is the third situational factor of this category, the adaptation must be feasible without severe negative consequences, especially for negatively affected stakeholders. If this adaptive capacity (*Ability to adapt*) is not given, for example, in the case of fishermen by a changeover to a new fishery product or new fishing methods, it has again financial and therefore even personal security implications, representing a severe detriment.

It was decided to differentiate between the *ability* to adapt to change and the *willingness* to adapt to change. In the context of the interviews, the first was related to given circumstances often outside of the sphere of influence of the affected person (such as policies), whereas the latter is understood here as the mental flexibility and positive approach towards change, which are within one's own scope of action (see Di Fabio and Gori 2016; Howard 2019). A lack of either of them is solely negatively influencing people's attitude.

Species-related factors

Not only the features of the perceiving individual, but also those of the object of perception—the factors related to a species itself—are significant for the formation of perception. The category species-related factors (marked green in Fig. 2) include also the species' interactions with the ecosystem, here in the form of *ecological effects* and *extent of the spread*. The latter is further divided into *mass occurrence* and *rarity*. Two seemingly opposing perspectives on mass occurrence are presented in the follow:

- 1) [on the Pacific oyster].
„**R:** [...] also how much they spread, and how many there are then, that that is also fascinating to see, in that moment, right.”
- 2) [on the Chinese mitten crab and Pacific oyster].

“**R:** *The Chinese mitten crab as such, when it occurs in great quantities, they are just nasty. And the same goes for the oysters. Right?*”

These contrasting evaluations of mass occurrence support the assumption that a person’s final perception is a product of several interacting factors and not single factor based. Conversely, *Rarity* was also found to be a determining factor.

Another species-related factor is the *Residence time* of the species. From the interviews, it could be deduced that a long residence time since introduction correlates with a higher acceptance. This can be explained with the achievement of a new equilibrium of the ecosystem, to the state of which the people mentally adapt within generations. A species that was introduced decades ago is therefore likely to be perceived as not bothering, as opposed to the sudden event of an introduction (for details see discussion of this paper; cf. *Change, novelty & willingness to adapt*).

Outer factors

As the name implies, outer factors (marked yellow in Fig. 2) influence our perception from the outside: through communication. Two specific mechanisms can be differentiated through which our opinions, our beliefs, and ultimately also our perception are formed. This is either content-related, as a source of our knowledge and information input, or language-related, relating to how a message is voiced. This includes potential bias in the presented topics as well as wording, narratives, and framing. Three domains were identified: the media, including social and print media, academics or science, and other people from our private sphere. Further ones are conceivable but were not mentioned in the interviews.

Discussion

Research on introduced species mainly aims at the ecological effects these have on the affected ecosystems and biodiversity. To expand the knowledge on social aspects of species introduction, an exploratory approach was undertaken in the context of the Wadden Sea in order to investigate (1) the effects marine neobiota have on the quality of life of people who live and work in the coastal area of the Wadden Sea and (2) the human perception of neobiota.

As demonstrated in the analysis, the two research foci explored in this study are strongly interrelated: the effects a species has on the ecosystem; Wadden Sea is one of the drivers of how people perceive and evaluate neobiota, which feeds back in the form of responses to species introductions (Howard 2019). Furthermore, our cognitive processes including perception influence what we experience as an effect and how much importance we attach to it (Howard 2019;

Shackleton et al. 2019b). As pointed out by Howard (2019), effects by introduced species might not be noticed or considered as affecting well-being, for example, if a species is not perceived to be introduced. In turn, people’s approach towards neobiota (research area 4 in Fig. 1) has implications for the initial drivers of species introductions (research area 1 in Fig. 1) and correlates with a good quality of life (research area 2 in Fig. 1; Di Fabio and Gori 2016; Howard 2019).

The number of codes was an indicator of how prevalent a topic was in the minds of the stakeholders and in the context of the interview. However, especially with respect to our findings relating to the first research question (How do marine introduced species in the Wadden Sea affect people’s lives? In which respect do people feel affected?), no final conclusions should be inferred from the number of codes, neither on the distribution of effects nor on how strongly the general life quality of residents of the Wadden Sea is influenced.

We showed that neobiota have an effect on many different areas of the lives of the respondents. A variety of immaterial effects of the quality of life could be identified, that were not yet documented for the Wadden Sea, such as *Knowledge and Education* or *Freedom of choice and action* (Table 3).

The share of non-material indicators slightly predominated in this study. This can be at least partly attributed to a pronounced sense of place of the stakeholders, i.e., a very personal and often emotional bond tied to the Wadden Sea itself. The Wadden Sea is inextricably linked with the lives of the selected stakeholders and is thus a part of their identity (Ratter and Gee 2012; Fish and Church 2014; García Rodrigues et al. 2022), which is demonstrated by the high coding frequency of *Sense of cultural identity*. A further reason for this distribution lies in the selection of interviewees, as some stakeholder groups primarily feel affected in material categories of their life quality, while to others these categories are less relevant. However, the reported effects have to be interpreted and seen in their contextuality: as such, multiple dimensions of GQL could be affected by a single change. Adverse effects on the fishery sector, for example, could not only result in decreasing food and income security (both material) but could also negatively affect this stakeholder group’s *Sense of cultural identity*, when fishermen identify with their profession as an integral part of their life or cultural heritage (Weeratunge et al. 2014; Díaz et al. 2015).

Even though effects associated with the non-material dimension were overall more prevalent in the interviews, both in the number of categories as well as of codes, there are strong indications for the assumption that non-material effects are generally often overlooked in current literature compared to its material counterpart (Díaz et al. 2018; Shackleton et al. 2019c; Shin et al. 2019; García Rodrigues et al. 2022). This is in line with IPBES stating that

narratives around good quality of life in global scenarios typically ignore such non-material dimensions (Shin et al. 2019). Shackleton et al. (2019c) also note that in many cases cultural impacts and benefits are treated only as an interesting anecdote that was stumbled upon during the research. Additionally, economic effects are far more frequently examined and assessed (Díaz et al. 2018; Shackleton et al. 2019c). This is in line with a review of studies on marine ecosystem services by Lique et al. (2013), which reveals a bias towards food provision, while less economically relevant contributions, for example, of esthetic and cognitive value, are less investigated and poorly understood.

The authors presume that the scientific methods generally used to acquire data on this research topic are not designed to identify immaterial changes. This may be related to the subjective nature of immaterial contributions often resulting as a consequence of a material effect, which makes assessment and quantification hard (Fish and Church 2014). Another possible reason is rooted in differences in the amount of importance attributed to the effects that are to be explored.

Although care has been taken in the interviews to balance questions and ask for positive and negative effects associated with introduced species likewise, detriments were more easily identifiable by the respondents. Explicit questions about positive effects sometimes even caused a certain confusion about the question on the part of the respondents. Especially in the fishery and shipping sectors, detrimental effects heavily outweighed benefits. However, to obtain more information on which stakeholder group experiences more positive or more negative effects, a larger data set of individual stakeholder groups is needed. As one respondent mentioned that negative effects are perceived more strongly, which is sustained by literature on *negativity bias* (Rozin and Royzman 2001), it is thinkable that positive aspects are less well-known or less visible. Furthermore, the establishment of a new species is always accompanied by changes, which are regardless of their nature often initially regarded with suspicion and rejection (Kueffer and Kull 2017). This effect is amplified when it comes to changes of something, in this case of the Wadden Sea, that people identify with and feel connected to (Ratter and Gee 2012). However, four respondents saw potential in these challenges, be it to understand and learn about the ecosystem of the Wadden Sea and its interactions, or be it as a driver for innovation for example through the utilization of neobiota (compare also García Llorente et al. 2008; Fish and Church 2014; García Rodrigues et al. 2022).

As mentioned in the previous section, not all stakeholder groups are equally involved and affected by species introductions. The level of awareness serves as an indicator of how much a person's life is entangled with neobiota or the ecosystem as contributing to one's quality of life.

In addition, a list of factors that have an influence on how stakeholders perceive neobiota was established (Table 4, Fig. 2). Albeit different in categorization scheme, it shares many common categories with frameworks of other authors that similarly explored people's perception of introduced species, such as the studies by Kueffer and Kull (2017), Kapitza et al. (2019), and Shackleton et al. (2019b). One major difference is this study's distinction of functions of categories, namely between awareness-raising and perception-influencing factors. Factors that were recognized also in the other studies as considerably influencing include *Effects*, *Knowledge*, and *Communication*. In line with Kueffer and Kull (2017), "beliefs" were identified as a cornerstone of perception change. This study suggests that attitudes are dynamic over time and can be adjusted by integrating new knowledge when new findings emerge. At least three respondents of our exploratory study have experienced a change in their attitude concerning the general introduction of species towards a more optimistic outlook. It was furthermore pointed out by respondents that risk perception and a negative attitude may change during the adaptation process. This is consistent with studies that investigated underlying psychological mechanisms of the often initial reactions of reluctance towards new species, resistance to change, or risk perception (e.g., Estévez et al. 2015). It was found that several factors such as increased knowledge, utility, or harmlessness of a species are able to mitigate these reactions. Humair et al. (2014) for example concluded that familiarity due to regular exposure ("mere exposure effect") and interaction with an introduced species promotes acceptance over time. This correlates with the residence time of species, which was also identified in this framework as influential, leading to species being assumed to be native when people have become accustomed to them (Humair et al. 2014). Other factors classified here as a belief and whose contribution to the formation of perception was confirmed in other studies include the significance attributed to the role of humans in the introduction process (Verbrugge et al. 2013) as well as beliefs about ecosystems and communities (Humair et al. 2014). Character traits or scientific interests have not been outlined in the other frameworks or only touched upon (see electronic supplement for the applied definitions). Demographic factors were noted in the interviews to some extent, but a larger data set would be needed to break this down further. Factors that are related to a political or historical context, as identified by Shackleton et al. (2019b), did not become visible in the interviews conducted for this research.

While the data material is not sufficient to determine a factor's specific influence in terms of direction and impact size, it was recognized that some factors correlate with a negative perception, whereas others are able to influence the attitude towards a balanced view. The analysis of the

interviews furthermore revealed that perception does not depend on single factors but often on complex interplays of multiple factors, which is exemplary for non-linear change and complexity (Kueffer and Kull 2017; Shackleton et al. 2019c; see also Glaser 2006).

With growing maritime traffic and increasing numbers of neobiota, the relevance of addressing species introductions has increased drastically, which is reflected in a growing research body, also in the Wadden Sea region (see Reise et al. 2023). As the social dimension is however still understudied, further research is needed (Bennett et al. 2017; Vaz et al. 2017; Markus et al. 2018). Qualitative approaches can help laying the groundwork of fundamental theory knowledge. Unfortunately, however, the qualitative PCI involves a significant amount of research effort per subject. This implies a comparatively low number of interviews, rendering it difficult to generate quantitative data. Furthermore, only one or two persons per stakeholder group were interviewed. Therefore, to further line the subject with knowledge, other research approaches such as quantitative, mixed methods, or participatory research approaches can effectively complement qualitative research findings (Kruse 2015; Bennett et al. 2017; Shackleton et al. 2019c). However, the aim of this study was not to achieve comparability, but to illustrate the broad spectrum of possible effects and perceptions, for which a small sample may well be sufficient. Therefore, we consider our exploratory study as an initiative to get important first insights on marine-human interactions in the context of species introductions in the Wadden Sea.

Topics of interest for future studies include long-term investigations that track developments over longer time periods of introductions, e.g., concerning trends of social effects, how they are experienced and adapted to (see Howard 2019), or on how perceptions change over the course of time. Spatial variations also remain to be addressed, comprising possible national differences or commonalities between the bordering countries of the Wadden Sea. Lastly, gaps in coverage of the range of interviewees should be closed by the inclusion of stakeholders often underrepresented in studies concerning neobiota such as tourists, policy makers, or residents not engaged in an occupation related to the Wadden Sea (see also Kapitza et al. 2019, Sijtsma et al. 2019). There were furthermore hints about neobiota being used for industrial applications (see, for example, Katsanevakis et al. 2014), which would suggest including the medical or chemical research industry as one stakeholder group. However, as no interviewee was found in this particular field, it had to be excluded from the sample.

Conclusion

This paper explored the human dimension of species introductions with respects to social effects and human perception.

From the interviews, it emerged firstly that social effects, as changes to the lives of people in the Wadden Sea Region, manifest themselves in very different ways. While some stakeholders are constrained in their occupational livelihoods, or to the contrary, derive a material benefit from neobiota, others are affected in their recreational behavior, in their thoughts and feelings, or in their cognitive experience of the Wadden Sea. In a few instances, on the other hand, changes are not perceived at all or only marginally. Overall, immaterial changes slightly outweighed material changes.

Additionally, the research offers information on how the evaluation of introduced species and their effects is shaped by a broad range of factors across multiple disciplines, including inter alia social, cultural, psychological, economic, linguistic, and institutional factors. Whether changes are perceived and to what extent depends on factors classified here as “awareness-raising,” while the question of how people experience neobiota and possible associated changes is determined by situational, outer, individual-related, and species-related factors. These were assembled into a framework that helps to comprehend how humans react to neobiota. It was however out of scope of this study to examine the size of the factors’ influence, their contextual variation, or how they operate in interaction with other factors.

For future research on (1) neobiota and (2) on the Wadden Sea, we recommend the following:

1. Implementation of diverse research approaches and designs from a variety of disciplines by embracing the potential of interdisciplinarity to diversify insights and to complement knowledge of identified research gaps across the research landscape of species introductions
2. Inclusion of a plurality of perspectives, values, and non-academic stakeholder groups into science and conservation
3. Fostering research on the human dimension in all four proposed research areas of marine-human relations concerning neobiota (Fig. 1) and how findings of one area translate to others, i.e., on how perception is reflected in and leads to people’s attitudes and actions
4. Examination of differences in effects and perception at temporal and spatial scales as well as among stakeholder groups

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Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval No animal testing was performed during this study.

Sampling and field studies The study does not contain sampling material or data from field studies.

Data availability The datasets generated and analysed during the current study are not publicly available due to the protection of the privacy of the interviewees but are available from the corresponding author on reasonable request.

Author contribution K. K. L. conceived and designed research. N. L. and C. B. helped with the design and contributed ideas and advice. K. K. L. conducted interviews and analyzed data. K. K. L. wrote the main body of the manuscript. N. L. and C. B. revised the manuscript and wrote text passages. All authors read and approved the manuscript.

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