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Physics of biologically populated seabeds

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The benthic biology has a big impact on the use of systems, on methods and work. Several factors complicate or even prevent the comprehensive view of the seafloor from the perspective of physics for operational use. The bio- and geosciences face a major challenge. Needed are interdisciplinary strategies to make progress. The goal must be a uniform description of the seafloor, which allows better predictions for burial processes, sound propagation, sediment transport or ecology in order to better protect and better use the oceans.

Benthos | *Biology* | *Geosciences* | *Underwater Sound* | *Modeling* | *Dominant Species* | *Generic Species* | *One Bio-Geo Seafloor*

Knowledge about the characteristics of the seafloor and its variability are comparatively low despite over a century of research. This is above all due to the high expenditure on the necessary infrastructure for measurements, essentially ships. Therefore many models were developed to describe the seafloor. They serve to predict physical properties in sparsely mapped areas.

With the increasing accuracy of the employed systems and data analyses, weaknesses of these model-based prediction approaches become obvious. Analyses regularly prove too simple model assumptions as the cause for the description of the seafloor. Often, the models of the seafloor consist of little more than a layered combination of sediments of different grain sizes. Ignoring the living components, their activity, and the effects of their presence, leads to an incomplete description of the causes and effects, that continually shape and alter the seafloor.

The growing economically motivated use of the shelf seas for pipelines and cables, for the production of energy, for aquaculture or fishing, but also for environmental issues and the removal of old ammunition, highlight the shortcomings. There is a consensus that a better, integrated and accurate description of the seabed would be helpful.

The greatest difficulties for the necessary integration of biology and geology into a uniform image of the seafloor result from the separation of marine research into the areas of its animated and its inanimate components. This strict separation led to a lack of consideration of the other discipline in both disciplines.

A good example of the separation consequences - in this case a lack of awareness - is provided by a sediment sample from a Mediterranean port (Fig. 1). It consisted of a dense network of calcareous tubes filled within mud. The analysis result of a geological laboratory was: 54.5% clay and 45.5% silt. The coarse, hard biological components were sorted out and have not been included in the report. Shells suffer the same fate: for geologists, they are often only a "biological component". They are often sorted out as an oversized component before a determination of the grain sizes, and are not considered further. For biologists, they are dead and thus no longer count as "biology", but only sediment. Shells are thus not regularly found in biology or geology databases.

Fig. 1: Sediment sample from a dense mesh of calcareous tubes, filled with silt, but also with a biological part. To be changed

The weaknesses of this separation of the specialist areas in the area of the seafloor are known. Various approaches have already been tried to take into account the biological components of the seabed and their influence on the physical and geological properties (eg Aller 1983, Murray et al 2002, Le Hir et al). Many authors succeeded in demonstrating correlations and mathematically describing locally valid relationships for data sets. However, it has never been possible to develop general and transferable relationships. The basic problem lies in an overly strong orientation to data and their explanation, rather than an examination of the interdependent (biological and geological) dependencies.

In this paper, we first show with selected examples the great influence of benthic biology on the use of systems, methods and work. Following this, we are present central difficulties which currently hinder or prevent a comprehensive view of the seafloor from the perspective of physics for operational use. We draw on our own practical experience.

For all of the listed challenges for science, we then discuss possible strategies to make progress. The goal must be a uniform description of the seafloor, which allows for better predictions for shipping, burial processes, underwater sound propagation, sediment transport or ecology.

Role of benthic biology

The benthos influences the processes and properties of the seafloor, both through presence and through activity. Both modes of action can produce completely different effects, than expected from the sediments alone. We present some selected effects.

- The use of unmanned vehicles, whether autonomous or remote controlled, is particularly hindered, often even prevented by high algae growing in the water column. This is particularly evident in kelp forests. Vehicles have already caught with their propellers the solid algae and have been lost.
- Commercial acoustic systems for offshore applications record the overall response of the seabed. This does not allow separation of the components according to the cause of the reflected signals. An increased roughness can be caused by sediments, corals, mussels and vegetation. Gas-producing bacteria can significantly increase the acoustic attenuation. Bivalves, sea urchins and tubes of digging worms increase the inhomogeneity of the top sediment as a point diffractor and influence the backscattering. At the same time, digging species can dissolve through their activity stratifications.

• The tubes of the *Lanice conchilega*, which protrude into the water, are made up of a large number of small glued particles shells. When massively occurring, they represent a large number of small sonar reflectors and lead to unexpectedly high back-scatter values of sandy mud seafloors.

• The same applies to the invasive American *Ensis*, which has been invading the North Sea since the 1980s. Vertically anchored in the ground, it protrudes several centimeters into the water column - up to 10 000 copies per square meter were observed off Belgium. Such a populated sand bottom will not permit sand ripple formation, and will exhibit completely different acoustic properties than the geological map suggests. Mussel occurrences of this density also prevent erosion processes, even promote sedimentation. Acoustic systems will "recognize" a very rough and hard ground.

• Mussels, sea urchins and worm tubes change the geo-mechanical properties of the seabed, leading to a significant increase in strength during vertical loading.

• Seagrass plays a special role with important effects. In dense meadows, it conceals the seabed from optical examinations. Adherent gas bubbles also prevent their acoustic examination. Sea grass also damps many of the forces acting on the seabed and provides a rich soil for digging fauna. Sedimentation occurs instead of expected erosion. As a result, thick rhizoms develop, as the sea-grasses react by further growth. Such seabeds are not adequately described by geological maps.

• For geoscientists, highly seasonal biological influences are unusual. Borsje (2012) showed off the coast of the Netherlands that the Lanice Conchilega worm can stop the movement of migrating bedforms in the summer with its dense tubes. Only with the death of the worms in the cold winter the mobile dunes move again.

These selected examples illustrate the important role of biology for the seabed, for its properties and processes. The decade-long strict separation of biology and geosciences in marine research makes it difficult to combine existing knowledge. The small exchange between the disciplines causes some of the existing difficulties, but solutions can be offered.

Challenges

In this section, we briefly summarize important aspects of the combination of biology and geology of the seabed. These challenges have hitherto prevented an interdisciplinary integrated study of the seabed. For the sake of simplicity, we consider the problem of integrating biological influences into geoscientific analyses. Basically there are similar difficulties for biologists to integrate physical results.

Challenge 1: Incompatible data formats in biology and geosciences

Geoscientists, when attempting to include biological information into their models, encounter the problem that the bulk of biological information (listing of species) is described in words. These cannot be processed in mathematical equations. It is easier to process accompanying data (eg abundances, which are given as numerical values).

Challenge 2: Large number of species

The attempt to better describe the seabed by taking into account biology often fails for the geoscientist in the large number of existing species. They are regularly confronted with the question of reducing this amount of information, ie taking relevant types into account and excluding others.

Challenge 3: Large number of similar species

In addition to the variety of species, similar species with minimal differences present a further challenge. Geoscientists cannot decide which species can be combined for a particular study or method and thus have an impact.

Challenge 4: Missing information on the abundance relevance

The seabed hosts many species with changing populations. For the various physical methods of geosciences, there is hardly any information about which critical occurrences a species must have in order to cause observable effects. The question as to the cumulative effect of similar species is equally open.

Challenge 5: Secondary effects

The sediments of the seabed are subject to external, largely predictable forces such as currents or waves. This does not apply to the living parts of the seabed. Survival strategies of different species lead to secondary effects that simple models have not yet taken into account. For example, biofilms can stabilize sediments by "sticking sand grains together". A physical model would predict a reduced sediment transport due to the stabilizing effect. On the other hand, biofilms attract fish that suspend the sediment when taking up the biofilms as food, and thus increase the erosion potential.

Challenge 6: Variable occurrence of species

Geoscientists consider regular variations of the forces (eg tides) in their models. These predictable changes are not a major challenge. Changing populations occurs less regularly, especially when triggered by external factors. This is explicitly not the seasonal changes caused by the influence of light or temperature, but those caused by the interaction of the species or by cold or low oxygen soil water (see also Challenges 7 and 8).

Challenge 7: Episodic changes in the occurrence of species

Unexpected, sudden changes in the occurrence of species present a particular challenge. Invasive species can, for example, completely change ("restart") a stable existing system. Such incidents are a fundamental change in the situation and have not yet been implemented in geoscientific models. A prominent example is the dominant appearance of the American Ensis in the North Sea since the middle of the1980s (eg Houziaux et al., 2011). Their occurrence in Europe is attributed to the spread of ballast water in shipping.

Challenge 8: Biological processes are intentional

All species that colonize the seabed pursue a survival strategy ("intention"). In following this strategy, they alter the sedimentary structure of the sea floor. One example is the destruction of strata by digging worms or bivalves. In contrast to this, the abiotic seabed reacts only passively to external forces (currents, waves). The consideration of activity and intention in ocean models and databases is a particular challenge.

Challenge 9: Information generation and storage

To achieve advances in science, completely new data structures and data forms will be required to convert biological information into mathematically usable and relevant parameters. The first work already takes place with special attention to online semantic databases.

Solution strategies

Strategies that allow at least a partial advance in simplifying the problems can be developed on the challenges listed. Some have been tested and are already delivering results. The solutions also include nonanalytical methods such as the modeling of ocean flooring scenarios.

The numbers of the following strategies correspond to the corresponding challenges.

Strategy 1: »Words to Numbers«

The translation of word descriptions into numerical values has already succeeded successfully for individual questions. Jenkins (1997 and 2002) implements the method (known as "word parsing") in the seabed information system dbSEABED

Biological and geological descriptions into numerical parameters. In doing so, cover descriptions are successfully and correctly translated into grain sizes. However, further approaches are also required.

Nonanalytic modules exist for digging activity including sediment repositioning and alteration of the stratification. The ratio of the length of the new surface along the created roughness ("coastal line") to the previously straight ground profile provides a measure of the roughness change (Wever and Jenkins 2013). The

Roughness and cavities created are required for acoustic prediction. Both parameters can be determined exclusively by modeling; Measuring them directly in situ is almost impossible.

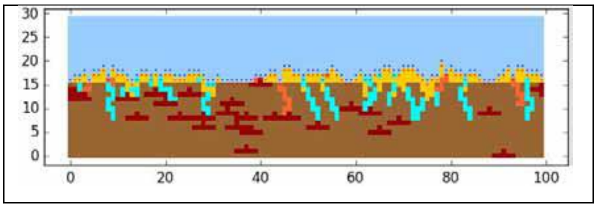

Fig. 2 shows the result of such a modeling. The original horizontal seabed (brown) with individual inhomogenities (mussels, pebbles: red brown) under a water layer (blue) was obtained by digging worms a relief. Living, digging worms (dark orange) leave water filled grave passages (light blue). Upward transported sediment is shown in orange. The blue-red dots represent the new water seabed border.

Strategy 2: Dominating organism

Difficulties arise from the variety of species. An important approach is to reduce information. This can be done in a first approach by concentrating on the "dominant kind". It is the species that has the greatest influence on a selected physical problem. For example, different dominant types are relevant for high-frequency and low-frequency acoustic applications. This strategy provides initial improvements over a "biology-free" model of the seabed. It can be refined by taking into account other species, which are important in the second place.

Strategy 3: Generic Types

The difficulty of several physically similar species can be countered by defining a "generic type". This represents the essential characteristics of various similar relevant or dominant species. The generic type must be defined for each physical method (or for all instruments used). It is conceivable in the future in biological databases of all kinds, a method-dependent generic type.

Strategy 4: Critical Occurrence

The critical occurrence of a species (or generic type) is the minimum number of its representatives that is required for a measurable impact on a physical measurement or problem. In connection with the dominant species, it must be noted that it must reach the critical occurrence, otherwise it can be neglected. The determination of the critical occurrence requires a joint new description of the seabed by biologists and geoscientists as well as an experimental validation.

Strategy 5: Analysis of coupled processes

The parameters that describe the variability of the physics of the biology-free seabed are manageable: waves, tides, consolidation and sediment transport. Relatively many processes can be modeled in coastal engineering. In this case, results of biological models as a time-variable input variable in models of the seabed physics. A promising new approach to the more complex, tightly coupled bio-geo systems lies in the simulation, in which biological representatives react to the physical environment, but also shape it. Other factors such as populations or nutrients can also be taken into account. Novel approaches for the simulation can be new technologies from unexpected fields of application, such as from biomedicine or the computer game industry. Fig. 3 shows a virtual seabed with objects in and on it. The model was created with established software for 3D printers. It is used to prepare the modeling of acoustic backscatter, as recorded by sonars.

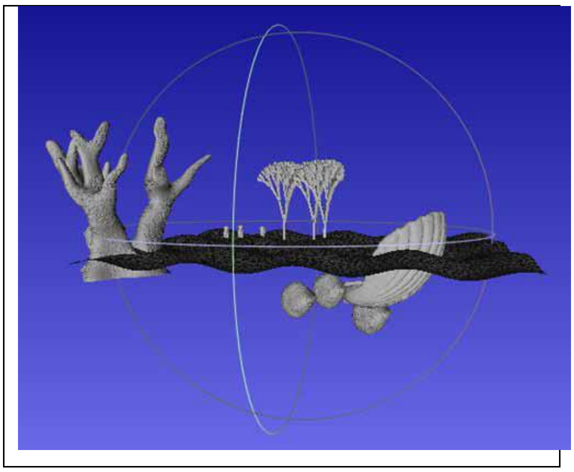

Fig. 3: Virtual seabed with objects

Strategies 6 and 7: Temporal variability

In addition to regularly changing forces (e.g., tides, light, temperature), an additional biologically induced variability must be taken into account: the contributions of reproduction and dominance. The accuracy of these approaches may not be sufficient to define real time-variable results, but could provide the error areas for single or rarely repeated sampling and observations. Like the regular time sequences, episodic events are an important factor that must be considered. This includes the effects of human activity. Invasive species can, for example, cause a completely new species distribution and change the character of the seabed. As a strategy, a "restart" may be required, the completely new situation description.

Strategy 8: Population Models

Marine biologists have developed numerous and diverse models that can contribute to the challenge of targeted biological activity. They should be used to describe both uncertainties and physically relevant (stable) final states. To name a few: models of population ecology (such as Lotka-Volterra calculations or Leslie matrix models), but also models of food chains (eg EcoPath, NOAA 2012). Some of the models also describe the "engineering activity" of different species in the seabed and other targeted activities.

Strategy 9: Information systems

To cover the global environment (but also at the national level) and to represent biological diversity, a comprehensive set of input parameters is required to enable a useful link between Bio and Geo. In many cases, the resources are already available, for example in the semantic databases World Register of Marine Species (WoRMS 2017) or Encyclopedia of Life (EoL), which are available online. Despite their size, the use of these systems does not require a complex infrastructure such as a new database or modeling software. Connections with APIs (application program interfaces) or other remote call capabilities can provide input data, save results, and even operate modeling modules. There are already examples of distributed modeling systems for land and sea areas (CSDMS 2017).

Discussion and summary

The disciplines of biology and geology tend to provide detailed knowledge of the seabed, which is not fully usable today. Within the disciplines, but even more so across borders, it is currently not possible to combine the knowledge into a uniform image. The separation of biosciences and geosciences is inevitable in many areas: predictions are suboptimal due to incomplete models of the seabed, the applicability of equipment is restricted under certain circumstances, and the interpretation of measurements can be incomplete. The current importance, in particular, of the shallow waters for economic, ecological and scientific questions requires the combining of specialized knowledge in a uniform way. This is necessary in particular for changes (eg climate) taking place. It

There is an urgent need to make better use of existing data and to develop a better understanding of the seabed. This can be seen in current initiatives that we can lead:

- In 2014, NATO commissioned experts to work on this issue in an international specialist team and to develop proposals for the future description of the seabed by 2017. The results will be made available to the public.
- In October 2016, the Volkswagen Foundation (Hanover) supported a three-day symposium with leading international Benthos biologists, underwater acoustics and geoscientists. The title of the symposium "The Ocean's Seafloor - One Bio-Geo System" illustrates the goal of an interdisciplinary collaboration. During the symposium, many of the participants began to work out joint bio-geo project proposals and plan joint research trips. Some participants even saw the origin of a new discipline in the symposium.
- For the 2017 anniversary of the Acoustical Society of America (December 2017 in New Orleans), the President of the Association announced her own Bio Geo Benthos event as a result of the symposium in Hanover.

- As a new focal point, integrated bio-geo research is planned for 2017 by at least one US institution.

Looking further into the future, the progress towards a unified and complete description of the sea floor, among other factors, is primarily determined by a better collaboration of bio- and geoscientists. Technological developments will help to bring together both disciplines. For example, acoustic monitoring - in principle a geophysical tool - can be used to record regular and occasional changes in biological populations. These in turn control geoacoustical properties over excavation structures and acoustic roughness Joint bio- and geo-projects during the sound propagation monitoring are conceivable. At the same time, it is highly significant that bio and geoscientists carry out joint expeditions, in particular that they collectively describe sediment cores and pictures. This will provide more accurate and complete descriptions and extend experience across boundaries. In order to achieve reciprocal benefits in the future, basic funding is required, but also a new perspective in project applications.

In this article, the fundamental question was presented mainly from the perspective of geoscientists. This should not mislead the goal of creating a holistic description of the sea floor. The term »One Bio- Geo Seafloor« is becoming increasingly established.

A holistic description must enable both biologists and geoscientists to extract the necessary parameters from existing databases from a single "seabed seafloor" system using adapted methods to better protect and better use the seas.
