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The sea slugs of *Shiroi Suna no Aquatope*

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Shiroi Suna no Aquatope (白い砂のアクアトープ) is a new anime by P.A. Works that started airing in the summer season of 2021 (Fig. 1). In a broad sense (to avoid spoilers), the anime focuses on the daily life of the staff working in a small aquarium in Okinawa. Its official title in English is *The Aquatope on White Sand* and, from this point on, we'll refer to it as *Aquatope* for simplicity.

Figure 1. Poster of *Shiroi Suna no Aquatope*. The protagonist Kukuru is the one holding the penguin. Source: MAL (www.myanimelist.net).

As expected of an anime about an aquarium, sea life features prominently in it. It is always great when a new series or game allows us to talk a bit about biology, so we'll just go ahead and take this opportunity. While you'll see plenty of penguins and fish in *Aquatope*, the typical fare of aquariums everywhere, we'll focus instead on the sea slugs. Yes, we know what you're thinking, "Eew, why slugs of all things?". But hey, they're quite cool and we hope you'll also think that way after you read a bit about them. Now let's get to it, shall we?

Figure 2. Screen captures of *Shiroi Suna no Aquatope* episode 15 (19:03 and 19:07). Kukuru goes on to say: "Sea slugs are full of mysteries. You wouldn't believe it, but they are a kind of sea snails. There's a ton of species and they are all different; some of them have camouflage, some of them have toxins. And they're just so colorful and pretty. I want more people to know how interesting sea slugs are."

WHAT'S A SEA SLUG?

Sea slugs are gastropod mollusks, which means that they belong to the Class Gastropoda inside the Phylum Mollusca. Class Gastropoda contains animals living in the sea, in freshwater, and on land; they are commonly known by names such as snails, slugs, limpets, and abalones.

Gastropods are a very diverse group of animals, with an estimate of 70,000 known species, with many still undiscovered (Rosenberg, 2014). Just to give you a point for comparison, that is more than all vertebrates (mammals, birds, "reptiles", amphibians, and fish) put together. The most diverse branch within Class Gastropoda is known as Infraclass Euthyneura, which counts for circa half of all gastropod diversity (Rosenberg, 2014).

It is thought that the more complex nervous system and sensory structures of euthyneuran gastropods allowed them to diversify in such a large group, with a wide variety of body shapes, and living in many types of habitats (Brenzinger et al., 2021). The Euthyneura contains many marine and freshwater families of gastropods and, notably, the vast majority of terrestrial species. It also contains all the lineages that we commonly refer to as 'sea slugs'.

'Sea slugs' is not a term that applies to a particular scientific grouping of animals. That is, it does not represent a single branch of the gastropod tree of life. Rather, it's a grab-all term for all marine gastropods that have a reduced shell or no shell at all. Shell reduction and shell loss evolved multiple times independently within gastropods, so the term 'sea slug' can be applied to all of the following groups: sea hares, sacoglossans (a.k.a. solar-powered sea slugs), headshield slugs, sea angels, and nudibranchs. The Japanese term for sea slugs is ウミウシ, *umiushi*. Taken literally, this word means 'sea oxen' or 'sea cattle', though the origins of this name are unclear.

In this article, we will focus mostly on nudibranchs for a few reasons. First, they are the most diverse group of sea slugs, and thus, they are what comes to mind with the term 'sea slug'. They also have the most colorful and amazing forms,[1] rendering them favorites among nature-loving people, wildlife photographers, and diving enthusiasts (Jensen, 2013; Hewitt et al., 2021; Fig. 3). And, finally, because the species from *Aquatope* that we will discuss are all nudibranchs.

Figure 3. The sea slug *Hypselodoris festiva*, photographed in Hong Kong by Ryan Yue Wah Chan, 2020. Source: iNaturalist (https://www.inaturalist.org/observations/42689203).

Formally, nudibranchs are animals belonging to Order Nudibranchia within the Euthyneura. The term 'nudibranch' comes from the Latin word for 'naked' and the Greek word for 'gills'. That name highlights the fact that the gills of these animals are "free-floating" so to speak (Fig. 4). The specific term for nudibranchs in Japanese is 裸鰓類, *rasairui*.

SEA SLUG BIOLOGY

Sea slugs evolved from populations of sea snails. Sea snails, as expected from snails, have hard calcareous shells. Throughout the evolutionary history of euthyneuran gastropods, natural selection has favored forms with smaller shells in some lineages. Those lineages eventually gave rise to the

[1] Though species of the genus *Melibe* are nightmare fuel. Check out this 2019 video by the Monterey Bay Aquarium: https://www.youtube.com/watch?v=VAle2HPkXcw

sea slugs we know today.

Having a reduced shell decreases the animals' immediate defensive capabilities against predators, but increases their mobility (Ponder et al., 2020). Just like deciding whether your character should have heavy armor, light armor, or no armor at all. Sometimes, evolutionary trade-offs work in a similar way to RPGs.

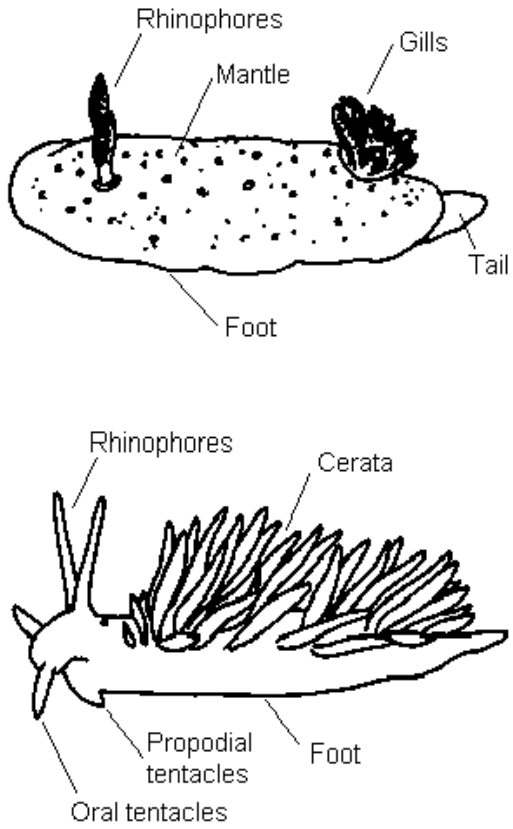

Figure 4. Simple diagrams of the two main nudibranch body plans: dorid nudibranchs (top) and aeolid nudibranchs (bottom). You can see the "naked gills" that give the group its name. In aeolids, the structure known as cerata function like gills. The rhinophores look like a pair of horns or ears, but are chemosensory organs (for taste and smell). Source: SeaSlug.org (https://www.seaslug.org.uk/).

Throughout millions of years, this trend in favoring smaller shells eventually resulted in the rise of forms with just a vestigial (and internalized) shell or even no shell at all. That gave sea slugs some ability to swim and also, the possibility of hiding in small crevices (Ponder et al., 2020). But then again, their defenses were impaired by the lack of a shell. Or were they?

Sea slugs rely on other sorts of defense mechanisms. They have colorful patterns that may help them camouflage themselves in their habitats (which includes colorful corals and sponges) or serve as a warning sign (Debelius & Kuiter, 2007). In nature, stark body colors and patterns (like a wasp's black and yellow stripes) often indicate that the animal is poisonous – or at least has an awful taste if eaten. That strategy is called aposematism and it is used to ward off potential predators.

The toxins of some nudibranchs, for instance, can kill predators like fishes and crustaceans (Debelius & Kuiter, 2007). Those toxins are obtained or derived from the slugs' main food items, which include animals such as sponges and ascidians (Fig. 5; Cheney et al., 2016).

Figure 5. The variable neon slug *Nembrotha kubaryana* obtains toxins from their ascidian prey (Paul et al., 1990). Source: Wikimedia Commons, photo by Alexander R. Jenner, 2009.

Some sea slugs can co-opt more defenses from their food source than any other animal. For instance, aeolid nudibranchs steal entire cells from corals and anemones (Fig. 6; Wägele & Klussmann-Kolb, 2005). These cells are called cnidocytes and are present in all cnidarians (this notably includes stinging jellyfish). Aeolid nudibranchs feed on those cnidarians, ingest their tissues, and somehow can retain the fully functional cnidocytes. They use the cnidocytes as an anemone would: to sting harassers. Naturally, the cnidocytes are functional only for a limited time in the nudibranch's body.

Figure 6. The Spanish shawl *Flabellinopsis iodinea* gathers stolen cnidocytes on the cerata on its back (the same structures that it uses for breathing). Source: Wikimedia Commons (cropped), photo by Yury Velikanau, 2016.

Some sea slugs can steal other types of cells that, although not as awesome as defensive stingers, represent an even greater feat. They steal chloroplasts from algae (Cartaxana et al., 2021; Maeda et al., 2021). That's right, those are the cells responsible for photosynthesis. The sea slugs known as sacoglossans can retain functional chloroplasts in their body, which essentially enable them, an animal, to photosynthesize like a plant. The chloroplasts act like an extra energy source for the sacoglossans, which gives them their common name 'solar-powered sea slugs'. Like the cnidocytes above, the chloroplasts are only functional for a limited time. One species of sacoglossans, known as sea sheep, went a bit viral on social media some years ago because it looks so damn cute (Fig. 7).

There are other ways in which sea slugs are awesome too. Some sea hares have giant neurons and this has allowed groundbreaking neurobiology research on learning and memory (Gillette, 1991). That research, in turn, has led to a deeper understanding of human neurobiology. The 2000 Nobel Prize in Physiology or Medicine was granted to researchers studying *Aplysia* sea hares.

Figure 7. The sea sheep *Costasiella* sp. Source: ND Awards (https://ndawards.net/winners-gallery/nd-awards-2014/macro/hm/802/), photo by Lynn Wu.

The next big thing for the crossover between sea slugs and medicine could be regeneration. The sacoglossan *Elysia marginata* can auto-decapitate, which means it can fully separate its head from its body. This is thought to be an extreme but controlled system to eliminate parasites (which remain in the body), while the head crawls away and then fully grows a new body (Mitoh & Yusa, 2021). The head can survive and obtain energy from all those stolen chloroplasts mentioned above.

SHIROI SUNA NO AQUATOPE

Sea slugs live in a variety of marine habitats worldwide, though the greatest diversity can be found in warmer waters, such as the Indo-Pacific and the Caribbean. There are circa 3,000 known species of nudibranchs globally and a bit over 1,000 of them are known to inhabit Japanese waters (Ono & Kato, 2020). Expectedly, there is a wealth of species from the warmer waters in Okinawa, where *Aquatope* takes place.

In episode 15 of *Aquatope*, protagonist Kukuru is tasked by her boss to come up with ideas for a special temporary exhibition. One of her ideas – and the one that her

boss greenlights – is an exhibit of umiushi (Fig. 8).

Figure 8. Kukuru's manager Tetsuji, as he greenlights her sea slug proposal. Screen capture of *Shiroi Suna no Aquatope* episode 15 (6:15).

Naturally, Kukuru chose an ensemble of nudibranch species that she could easily find (and capture) on the shores of Okinawa (Fig. 9). So let us talk a bit about the species she listed.[2] It's a great opportunity to go over some cool biology facts and an even better chance to show some amazing photographs. The information in the next section comes from Debelius & Kuiter (2007) and Ono & Kato (2020) unless otherwise noted.

Figure 9. Screen capture of episode 15 (6:20) of *Shiroi Suna no Aquatope* showing the nudibranch species Kukuru proposed for the aquarium's special umiushi exhibition. See the Appendix in the end of this article for the translation of Kukuru's notes.

Ardeadoris cruenta (Family Chromodoridae): The species' Latin name cruenta means 'bloody' or 'stained with blood' (Brown, 1954), a reference to the red spots around the slug's mantle that look like drops of blood (Fig. 10). In older scientific literature, it was classified in a different genus, under the name *Glossodoris cruenta*. Though the species doesn't have a vernacular name in English, Ardeadoris cruenta is known as アカテンイロウミウシ in Japanese (akaten iroumiushi). 'Akaten' means 'red dot(s)' and the term 'iroumiushi' is used to refer to members of the family Chromodoridae in general.

This species can be found throughout the tropical Western Pacific, from Okinawa to Australia. The animal typically measures between 3 and 4 cm (Rudman, 1986), but can reach up to 5 cm. It feeds on sponges.

Figure 10. *Ardeadoris cruenta*. Source: Wikimedia Commons, photo by Chad Ordelheide.

Tambja sagamiana (Family Polyceridae): This species was named after the place where it was first discovered, Sagami Bay, just to the south of Tokyo. Its name in Japanese is サガミリュウグウウミウシ (Sagami ryūgūumiushi). The term 'ryūgūumiushi' applies to members of the family Polyceridae.[3]

[2] There are a few more species that appear in the episode, but we won't talk about all of them. Otherwise, this article would become way too long.

[3] While we could not find enough evidence explaining the vernacular Japanese name for polycerids, the term 'ryūgū' is the name of the legendary undersea dragon palace particularly famous as Ryūgū-jō from the tale of Urashima Tarō. 'Ryūgū' is used in other marine species names to indicate animals that look particularly superb or mystical, or that live deep in the sea. It has been used, for instance, for giant oarfish (*Regalecus glesne*), sea stars (phylum Echinodermata; Kogure et al., 2009) and mud dragons (phylum Kinorhyncha; Yamasaki, 2016).

This species lives in waters around Japan, Korea and Taiwan. The animals can grow to 13 cm and feed on bryozoans (Pola et al., 2006).

Figure 11. *Tambja sagamiana*. Source: 世界のウミウシ [Seaslug World] (https://seaslug.world/species/tambja_sagamiana), photo by Manabu Kakegawa, 2016.

Goniobranchus coi (Family Chromodorididae): This species was named in honor of the person who collected the first specimen in Vietnam, whose name was M. Nguyen-van-Co (Risbec, 1956). The masculine genitive (possessive) case in Latin renders 'Co' into 'coi'. Its Japanese name is シラナミイロウミウシ (shiranami iroumiushi); 'shiranami' means 'white-capped waves'.

The species can be found throughout the tropical Western Pacific, from Japan to Australia. It measures circa 6 cm and feeds on sponges.

Figure 12. *Goniobranchus coi*. Source: 世界のウミウシ [Seaslug World] (https://seaslug.world/species/goniobranchus_coi), photo by Akihito Iwakiri (oasis), 2018.

Phyllidia coelestis (Family Phyllidiidae): The name coelestis means 'of the sky' and is a refence to this slug's blue color (Fig. 13). Its name in Japanese is ソライロイボウミウシ (sora iroiboumiushi). The term 'iroiboumiushi' refers to members of family Phyllidiidae (イロ and イボ mean 'colorful' and 'wart(s)'), while 'sora' refers to its sky color.

This species is very widespread and can be found from Japan, throughout the Indo-Pacific, to South Africa. It measures about 6 cm in length and feeds on sponges.

Figure 13. *Phyllidia coelestis*. Source: 世界のウミウシ [Seaslug World] (https://seaslug.world/species/phyllidia_coelestis), photo by Manabu Kakegawa, 2016.

Dermatobranchus ornatus (Family Arminidae): The name ornatus means simply 'ornate'. It doesn't mean much, as countless species in all animal groups bear some form of the name "ornate"; besides, *D. ornatus* is not particularly more ornate than other nudibranchs. Its Japanese name is ハナオトメウミウシ (hana otome umiushi). The name 'otome umiushi' refers to members of the genus *Dermatobranchus* ('otome' means 'girl'), while 'hana' means 'flower' or 'flowery'.

This species is distributed throughout the Indo-Pacific, from Japan to Oman. It can reach 8 cm in length and feeds on gorgonian corals (Zhang et al., 2006).

Figure 14. *Dermatobranchus ornatus*. Source: 世界のウミウシ [Seaslug World] (https://seaslug.world/species/dermatobranchus_ornatus), photo by Manabu Kakegawa, 2016.

THE UNKNOWNS

One important point that Kukuru makes is that despite the best efforts of researchers, actually very little is known about sea slugs (Fig. 15). We can identify them to some extent, though many species undoubtedly still await to be discovered. We have even learned a few things about their toxins and their ability to steal cnidocytes and chloroplasts, as we mentioned above. But for the vast majority of species out there, we still don't know much: what they eat or what eats them, their reproduction, seasonality, behavior – the list goes on. More urgently, we don't have much of an idea about how they will respond to increasing global temperatures and ocean acidification. There is still plenty to be studied about these fantastic creatures.

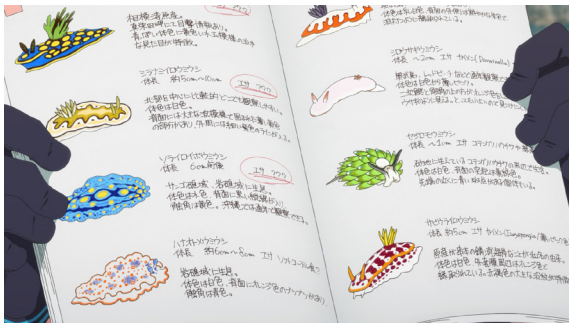

Figure 15. Kukuru shows her notebook, telling her friends how much we don't know about sea slugs: the entries marked in red represent missing data regarding the slugs' diet. Screen capture of *Shiroi Suna no Aquatope* episode 15 (10:18).

UMIUSHI IN JAPAN

Although invertebrate animals such as slugs rarely are in the spotlight (Black et al., 2001; Salvador et al., 2021), umiushi seem to hold a special niche with the public in Japan. We will briefly go over some examples below.

Video games

There are some nice examples of umiushi in Japanese video games, the most prominent of which is of, course, *Pokémon*.[4] Both forms of Shellos and Gastrodon are based on real-life species of nudibranchs belonging to the genera *Chromodoris* and *Hypselodoris*.[5] Goomy was based on species of the genus *Goniobranchus* (Fig. 12), and both Phione and Manaphy were based on the sea angel *Clione limacina*. You can find more information about all mollusk Pokémon in the article of Salvador & Cavallari (2019).

Sea slugs can also be found in *Animal Crossing* games (Nintendo), together with sea angels.[6] The sea slug is *Hypselodoris fes-*

[4] This relationship goes the other way too. The species *Thecacera pacifica* was discovered in the Indo-Pacific and described in the late 19th century, but has recently been dubbed the "Pikachu slug" because its body is completely yellow with the exception of the tips of its rhinophores and gills, which are black.

[5] Though East Sea Gastrodon, in particular, might bring in some design choices from sea hares (Salvador & Cavallari, 2019).

[6] Sea angels are called "sea butterflies" in the English translation of the games. Sea slug: https://animalcrossing.fandom.com/wiki/Sea_slug / Sea butterfly: https://animalcrossing.fandom.com/wiki/Sea_butterfly

tiva (Fig. 3) and the sea angel is *Clione limacina*, like in *Pokémon*. *Puzzles & Dragons* (GungHo Online Entertainment, 2012) also has its nudibranch: the Great Witch's Disciple, Ponno (大魔女の弟子・ポンノ).[7] Its design was inspired by *Hypselodoris apolegma*,[8] the same species that was likely the inspiration for West Sea Shellos in *Pokémon*.

Sea angels were the likely inspiration for the Moon Slug (ツキミアゲ)[9] from *Monster Hunter: World* (Capcom, 2018). In *Monster Hunter Rise* (Capcom, 2021), there is the Monksnail (ウミウシボウズ, 'umiushi bōzu'),[10] which is a play on the words umiushi and the name of a yōkai, umibōzu (海坊主, sea monk). The design of the Monksnail is based partly on a generic nudibranch (its body) and part on depictions of the head of a umibōzu (its "shell").

A further example is the monster Oilboyle (オイルシッパー)[11] from *Final Fantasy VIII* (Squaresoft, 1999), which has a design somewhat reminiscent of nudibranchs like the blue sea dragon *Glaucus atlanticus*.

If we go way back in time to the 16-bit era, we can also find some umiushi-inspired creatures. *Demon's Crest* (デモンズブレイゾン) (Capcom, 1994) has a boss called Holothurion[12] that looks like a gigantic demonic snail, but its blue soft body might have some design choices inspired by nudibranchs such as *Chromodoris willani* and *Glaucus atlanticus* (Cavallari, 2015).

Another one is the Sea Slug (うみうし, umiushi) from *Dragon Quest II* (Enix, 1987), now known as Merlusc.[13] It is supposedly a purple sea slug, but it has only a generic cartoon-like slug design. It is just a different color from the yellow Maulusc, which is a terrestrial slug. Anyway, we cannot be too strict with the art of a 1987 game.

Last but not least, we need to acknowledge a umiushi from the *Kirby* franchise, though this one comes from the anime, not the game. The so-called Great Sea Slug Monster (ウミウシ大魔獣)[14] from *Kirby: Right Back at Ya!* (星のカービィ; Studio Sign & Studio Comet, 2001–2006) was based on the species *Hypselodoris festiva* (Fig. 3).

The list above is by no means exhaustive – it just reflects the games we played. We must have missed quite a few examples, so please feel free to write to us if you come across more umiushi in other Japanese games.

Toys and collectibles

If you look at Japan's thriving commerce of game and anime goodies, you'd be excused to think that this "toys" boom is a current phenomenon. However, toys were a vibrant part of Japanese culture ever since the Edo Period (Ryōsuke, 1990; Alt, 2020). And more than that, after Japan opened up to the rest of the world in the mid-19th century, its toys rose to prominence in the global market, going up against the then leader Germany in the first half of the 20th century (Sadao, 1967; Phoenix, 2006).

After a sad pause in their production during World War II, toys helped kickstart Japanese economy and bounced back to the forefront of Japanese exports, to the extent that by the end of the 1950s Japan had

[7] https://www.appbank.net/2020/04/09/iphone-application/1880493.php

[8] The similar *Hypselodoris variobranchia* was described too recently.

[9] https://monsterhunterworld.wiki.fextralife.com/Moon+Slug

[10] https://monsterhunterrise.wiki.fextralife.com/Endemic+Life

[11] https://finalfantasy.fandom.com/wiki/Oilboyle

[12] https://www.spriters-resource.com/snes/demonscrest/sheet/13689/

[13] https://dragonquest.fandom.com/wiki/Merlusc

[14] https://wikirby.com/wiki/Great_Sea_Slug_Monster

around three quarters of the global market (Sadao, 1967; Alt, 2020). Japanese toys were not only cheap overseas back then, but were also of excellent quality and artisanship.[15] That rich background fed into the "cult of kawaii", spearheaded by Sanrio, and the overall otaku culture that extends to this day (Wallin & Sandlin, 2020). Today, of course, most plastic toys are made in China or elsewhere, but to the specifications of Japanese companies such as Sanrio.

True to this long-standing tradition, there are plenty of umiushi toys around Japan. They go from gacha capsule toys to meter-long plush toys. And all of them are as kawaii as you could expect.

Charles Eames, one of the most influential industrial designers of the last century, once said: "Toys and games are the preludes to serious ideas." Eames was thinking about the industry and "just" talking about creativity and innovation. But we can take this sentence one step further: playfulness, including toys, is something that facilitates education. This is not only widely recognized by educators everywhere (for instance, Raw, 1982; Stein & Miller, 1997; Swiniarski, 2012), but also by the characters in *Aquatope*. In episode 18, they use a cosplay event and a "hunt" for stickers to raise awareness about some species of fish and other marine life that are not particularly popular.

It could be argued that toys of unusual animals (that is, non-mammal) such as umiushi can increase awareness and thus open venues for education. The knowledge obtained about said animals will hopefully lead to a greater appreciation and more positive attitudes. Such public awareness and appreciation are certainly lacking in regards to invertebrate animals and is considered a major cause of the lack of protection and conservation efforts directed at them (New, 1993; Knight, 2008).

Figure 16. Example of umiushi toys: the gacha series ウミウシドラゴン　マスコットフィギュア ("dragon-nudibranch mascot figures") by Qualia Co., 2021. Source: Qualia (https://qualia-45.jp/distinations/umiushidragon_mf/).

Aquariums

While toys and presence in pop culture certainly help to increase awareness of animals and conservation among the public (Salvador, 2017), few things – if any – can substitute the real deal. As such, having "contact" with live animals in aquariums is what will make the message stick, as recognized by *Aquatope*'s protagonist, Kukuru. And Japanese aquariums seem to be doing an excellent job in this regard, with many thematic umiushi exhibitions.

In 2021, Oga Aquarium GAO (男鹿水族館ガオGAO, in Akita Prefecture), the Shellfish Museum Palais la Mer (貝の博物館 ぱれ・らめーる, in Ōshima, Tokyo), and Teradomari Aquarium (寺泊水族博物館, in Niigata Prefecture) had umiushi-themed exhibitions.[16] Another recent exhibition took place at Shinagawa Aquarium (しながわ水

[15] A miniature of the Cadillac produced in the 1950s in Japan was so expensive as to be considered a luxury item according to local laws (Alt, 2020). That's something like the ancestor of the many fancy collectibles that dry our wallets to this day.

[16] Oga Aquarium GAO: https://www.gao-aqua.jp/event/32535.html / Shellfish Museum Palais la Mer: https://bit.ly/3Di6eCL / Teradomari Aquarium: https://www.ohbsn.com/radio/programs/snp/2021/01/029392.php.

族館, in Tokyo; Fig. 17) in 2018.[17] The year of 2021 was timely to feature umiushi because that was the year of the ox in the Chinese zodiac; as we explained above, umiushi means "sea oxen" in Japanese. But you can see lovely umiushi any time in places like the Kaiyukan (海遊館, in Osaka).[18]

Figure 17. Poster for the exhibition at Shinagawa Aquarium, 2018. Source: Fashion Press (https://www.fashion-press.net/news/41030).

The mascots of Awashima Marine Park (あわしまマリンパーク, in Numazu; Fig. 18) are a pair of umiushi siblings named Umine Awashima (淡島 うみね) and Otome Awashima (淡島　おとめ).[19] Their designs were inspired, respectively, by the fan-favorite *Hypselodoris festiva* (Fig. 3) and *Dermatobranchus albopunctulatus*. The latter is a species of otome umiushi, of course. A third mascot, and friend to the siblings, is Mashiro Uchiura (内浦　ましろ), whose design was based on *Hypselodoris placida*.

Figure 18. The mascots of Awashima Marine Park. From left to right: Umine, Otome, and Mashiro. Source: Awashima Marine Park (http://www.marinepark.jp/umine/).

Aquariums (and zoos) are institutions devoted to education (and edutainment), research, and animal conservation. It is an obvious fact, as related by Kukuru's manager Tetsuji in *Aquatope*, but it needs to be repeated here. The importance of these institutions in those three fields, but particularly in education, is undeniable (Packer & Ballantyne, 2010). However, there is growing concern about animal welfare in zoos and aquariums.

While part of those concerns is just the loud and typically nonsensical Twitter/Facebook outrage, this is an issue of utmost importance – especially concerning the entertainment factor (Carr & Cohen, 2015). Animals should be treated humanely and zoos and aquaria are striving to reach higher standards of welfare (Norton et al., 1995; Maple & Perdue, 2013). So, it was really good to see Kukuru fighting so hard in *Aquatope* to ensure her umiushi had the best conditions possible.

Sea slugs are notably difficult to keep in captivity due to their strict feeding habits,

[17] Shinagawa Aquarium: https://www.museum.or.jp/event/91377.

[18] Kaiyukan Satellite Gallery: https://www.kaiyukan.com/thv/marketplace/event/detail.php?id=6061. See also their Facebook profile for more info: https://www.facebook.com/umiushi.kaiyukansatellitegallery.

[19] http://www.marinepark.jp/umine/

dependent on specific corals and sponges (Calado & Dinis, 2005).[20] This fact is something that Kukuru repeatedly reminds everyone about and is at the forefront of her concerns about the animals' wellbeing (Fig. 19). This is of particular importance because Japan has a track record of poor performance in all global measures of animal welfare (World Animal Protection, 2020).

Figure 19. Kukuru worries that she has the wrong type of sponge to feed her *Tambja sagamiana*. Screen capture of *Shiroi Suna no Aquatope* episode 15 (12:18).

CONCLUSION

We certainly hope we've given you, dear reader, the chance to appreciate sea slugs. But we are just secondary players here. The actual work was done by the people behind *Aquatope*, who managed to bring actual knowledge of marine life into an entertaining anime.

Figure 20. Screen capture of *Shiroi Suna no Aquatope* episode 15 (19:28).

Invertebrate animals typically come across as ugly or even repulsive creatures to the public. But given the chance, most people will be able to recognize their amazing diversity and complex evolutionary history, and maybe even to appreciate some of those animals (Cardoso et al., 2011).

Ultimately, awareness and knowledge of how important invertebrate animals are for the ecosystem should feed into efforts to preserve them (Czekanski-Moir & Rundell, 2020). After all, if current trends go on unchecked and ecosystems collapse, it's our survival that's at stake.

Case in point, the franchise *Kemono Friends* (けものフレンズ) was able to draw more people to zoos in Japan and increase the amount of Google searches and Wikipedia views about the animals it featured (Fukano et al., 2020). Furthermore, it also drove people to donate more money to zoos and conservation funds related to those animals (Fukano et al., 2020). While *Aquatope* does not have a kemonomimi army like *Kemono Friends* to attract people's attention and yen, let us hope it has enough heart and biology to renew interest in aquariums and generate some funding to study and protect our oceans and their inhabitants.

REFERENCES

Alt, M. (2020) Pure Invention: How Japan Made the Modern World. Constable, London.

Black, S.H.; Shepard, M.; Allen, M.M. (2001). Endangered invertebrates: the case for greater attention to invertebrate conservation. Endangered Species Update 18: 42–50.

Brenzinger, B.; Schrödl, M.; Kano, Y. (2021) Origin and significance of two pairs of head tentacles in the radiation of euthyneuran sea slugs and land snails. Scientific Reports 11: 21016.

Brown, R.W. (1954) Composition of Scientific Words. R. W. Brown, Baltimore.

Calado, R. & Dinis, M.T. (2005) Nudibranchs in the marine aquarium trade industry. Portugala 5: 17.

[20] One reason why some nudibranch species can eat only a few types of sponges could be because each species can only deal with a limited variety of sponge toxins (Cheney, 2016).

Cardoso, P.; Erwin, T.L.; Borges, P.A.V.; New, T.R. (2011) The seven impediments in invertebrate conservation and how to overcome them. Biological Conservation 144: 2647–2655.

Cartaxana, P.; Rey, F.; LeKieffre, C.; Lopes, D.; Hubas, C.; Spangenberg, J.E.; et al. (2021) Photosynthesis from stolen chloroplasts can support sea slug reproductive fitness. Proceedings of the Royal Society B. 288: 20211779.

Cavallari, D.C. (2015) Shells and bytes: mollusks in the 16-bit era. Journal of Geek Studies 2(1): 28–43.

Cheney, K.L.; White, A.; Mudianta, I.W.; Winters, A.E.; Quezada, M.; Capon, R.J.; et al. (2016) Choose your weaponry: selective storage of a single toxic compound, latrunculin A, by closely related nudibranch molluscs. PLOS ONE 11: e0145134.

Czekanski-Moir, J.E. & Rundell, R.J. (2020) Endless forms most stupid, icky, and small: the preponderance of noncharismatic invertebrates as integral to a biologically sound view of life. Academic Practice in Ecology and Evolution 10: 12638–12649.

Debelius, H. & Kuiter, R.H. (2007) Nudibranchs of the World. IKAN, Frankfurt am Main.

Fukano, Y.; Tanaka, Y.; Soga, M. (2020) Zoos and animated animals increase public interest in and support for threatened animals. Science of the Total Environment 704: 135352.

Gillette, R. (1991) On the significance of neuronal giantism in gastropods. Biological Bulletin 180: 234–240.

Hewitt, S.J.; Picton, B.E.; DuPont, A.; Zahner, T.M.; Salvador, R.B. (2021) New records of marine molluscs from Saba, Caribbean Netherlands. Basteria 85: 59–72.

Jensen, K.R. (2013) Sea slugs – divers' favorites, taxonomists' problems. Aquatic Science & Management 1: 100–110.

Knight, A.J. (2008) "Bats, snakes and spiders, Oh my!" How aesthetic and negativistic attitudes, and other concepts predict support for species protection. Journal of Environmental Psychology 28: 94–103.

Kogure, Y.; Kaneko, A.; Nonaka, M.; Mah, C. (2009) A rarely encountered oreasterid sea star, Astrosarkus idipi (Echinodermata, Asteroidea), newly recorded from Japanese waters. Journal of the Biogeographical Society of Japan 11: 73–76.

Maeda, T.; Takahashi, S.; Yoshida, T.; Shimamura, S.; Takaki, Y.; Nagai, Y.; et al. (2021) Chloroplast acquisition without the gene transfer in kleptoplastic sea slugs, *Plakobranchus ocellatus*. eLife 10: e60176.

Maple, T.L. & Perdue, B.M. (2013) Zoo Animal Welfare. Springer, Berlin.

Mitoh, S. & Yusa, Y. (2021) Extreme autotomy and whole-body regeneration in photosynthetic sea slugs. Current Biology 31: PR233–R234.

New, T.R. (1993) Angels on a pin: dimensions of the crisis in invertebrate conservation. American Zoologist 33: 623–630.

Norton, B.G.; Hutchins, M.; Stevens, E.F.; Maple, T.L. (1995) Ethics on the Ark: Zoos, Animal Welfare, and Wildlife Conservation. Smithsonian Institution, Washington, D.C.

Packer, J. & Ballantyne, R. (2010) The role of zoos and aquariums in education for a sustainable future. New Directions for Adult & Continuing Education 2010(127): 25–34.

Paul, V.J.; Lindquist, N.; Fenical, W. (1990) Chemical defenses of the tropical ascidian *Atapozoa* sp. and its nudibranch predators Nembrotha spp. Marine Ecology Progress Series 59: 109–118.

Phoenix, W. (2006) Plastic Culture: How Japanese Toys Conquered the World. Kodansha International, Tokyo.

Ponder, W.F.; Lindberg, D.R.; Ponder, J.M. (2020) Biology and Evolution of the Mollusca. Volume 2. CRC Press, Boca Raton.

Ono, A. & Kato, S. (2020) 新版 ウミウシ: 特徴がひと目でわかる図解付き. Nudibranchs & Sea Slugs Illustrated. Seibundo Shinkosha, Tokyo.

Pola, M.; Cervera, J.L.; Gosliner, T.M. (2006) Taxonomic revision and phylogenetic analysis of the genus *Tambja* Burn, 1962 (Mollusca, Nudibranchia, Polyceridae). Zoologica Scripta 35: 491–530.

Raw, I. (1982) Science toys for science education. Impact of Science on Society 32: 467–472.

Risbec, J. (1956) Nudibranches du Viet-Nam. Archives du Muséum National d'Histoire Naturelle, Series 7, 4: 5–34.

Rosenberg, G. (2014) A new critical estimate of named species-level diversity of the recent Mollusca. American Malacological Bulletin 32: 308–322.

Rudman, W.B. (1986) The Chromodorididae

(Opisthobranchia: Mollusca) of the Indo-West Pacific: the genus Glossodoris Ehrenbergh (=Casella, H. & A. Adams). Zoological Journal of the Linnean Society 86: 101–184.

Ryōsuke, S. (1990) The simplicity and warmth of traditional toys. Japan Quarterly 37: 63–67.

Sadao, M. (1967) The Japanese toy industry. Japan Quarterly 14: 230–234.

Salvador, R.B. (2017) The unexplored potential of video games for animal conservation. Tentacle 25: 3–5.

Salvador, R.B. & Cavallari, D.C. (2019) Pokémollusca: the mollusk-inspired Pokémon. Journal of Geek Studies 6(1): 55–75.

Salvador, R.B.; Tomotani, B.M.; O'Donnell, K.L.; Cavallari, D.C.; Tomotani, J.V.; Salmon, R.A.; Kasper, J. (2021) Invertebrates in science communication: confronting scientists' practices and the public's expectations. Frontiers in Environmental Science 9: 606416.

Stein, M. & Miller, D. (1997) Teaching with toys: playthings offer serious help with science concepts. The Science Teacher 64(4): 22–25.

Swiniarski, L.B. (1991) Toys: universals for teaching global education. Childhood Education 67: 161–163.

Wägele, H. & Klussmann-Kolb, A. (2005) Opisthobranchia (Mollusca, Gastropoda) – more than just slimy slugs. Shell reduction and its implications on defence and foraging. Frontiers in Zoology 2: 3.

Wallin, J.J. & Sandlin, J.A. (2020) Plastic fantasies: globalization and the Japanese cultural imaginary. Cultural Studies ↔ Critical Methodologies 20: 524–534.

World Animal Protection. (2020) Animal Protection Index (API) 2020. Japan: ranking E. Available from: http://api.worldanimalprotection.org/sites/default/files/api_2020_-_japan.pdf (Date of access: 12/Nov/2021).

Yamasaki, H. (2016) Ryuguderes iejimaensis, a new genus and species of Campyloderidae (Xenosomata: Cyclorhagida: Kinorhyncha) from a submarine cave in the Ryukyu Islands, Japan. Zoologischer Anzeiger 265: 69–79.

Zhang, W.; Gavagnin, M.; Guo, Y.-W.; Mollo, E.; Cimino, G. (2006) Chemical studies on the South China Sea nudibranch *Dermatobranchus ornatus* and its suggested prey gorgonian *Muricella* sp. Chinese Journal of Organic Chemistry 26: 1667–1672.

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About the authors

Dr. **Rodrigo Salvador** is a malacologist – that's a weird word that means he researches mollusks. He specializes in the study of land snails but has always been interested in nudibranchs (West Sea Gastrodon is one of his favorite Pokémon). Notably, it is dangerous to leave him alone in Japanese aquarium shops: he will buy lots of nudibranch merch.

Ken Kuroki is a PhD student of bioinformatics, a field of study where, according to him, "computer geek meets biology." Sounds fun, right? He also runs a YouTube channel named Yurufuwa Biology with his friends to play various video games and enjoy super nitpicky details from the viewpoint of geeks and biologists.

APPENDIX

Here you can find the translation of Kukuru's notes (screen capture showed in Fig. 9).

アカテンイロウミウシ

黄色い体色と赤い水玉模様が目を引くウミウシダイバーの人気者。学名のArdeadoris cruentaのCruentaは「血だらけの」という意味。かわいい見た目とは裏腹に恐ろしい名前を秘めているウミウシです。

[Its yellow body color and red polka dots make it a popular choice for nudibranch divers. In its scientific name, *Ardeadoris cruenta*, Cruenta means "bloody". Despite the cute appearance, this nudibranch has a frightening name.]

サガミリュウグウウミウシ

何だか毒々しい見た目をしているこちらの海牛は名前に「サガミ」とあるように最初に確認されたのが相模湾だったことから由来しています。ウミウシの中では10 cm ほどと大型の部類に入ります。

[In the name of this nudibranch is "Sagami", which comes from the fact that it was first found in Sagami Bay. It is one of the larger nudibranchs, measuring about 10 cm in length.]

シラナミイロウミウシ

触覚からエラにかけて波のような模様が背中全体を囲んでいるのが特徴的。波の穏やかな岩礁域に生息しており、外套膜をヒラヒラとさせて動く活発な性格のウミウシです。

[It is characterized by the wave-like pattern that surrounds its entire back from the antennae to the gills. It lives in reefs where the waves are calm, and is an active nudibranch with a fluttering mantle.]

ソライロイボウミウシ

沖縄でよく見られるウミウシの一種で、背中にオレンジ色のイボがあるのが特徴。他の海牛より体の表面が少し堅く、ザラザラしています。

[A type of nudibranch commonly found in Okinawa, characterized by the orange warts on its back. The surface of its body is a little harder and rougher than other sea slugs.]

ハナオトメウミウシ

多種多様な色、見た目をしているウミウシたちですが、オトメと名前がつくウミウシの仲間は基本的に白い色がベースで、「清楚」、「華蓮」なイメージがぴったりだと思っています。こちらのウミウシも名前の通りかわいらしい見た目をしています。

[Nudibranchs come in a wide variety of colors and appearances, but the nudibranchs with the name "Otome" are basically white in color, which I think gives them the perfect image of "neatness" and "floweriness". This nudibranch also has a cute appearance as its name suggests.]