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Maritime environment health risks related to pathogenic microorganisms in seawater

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ABSTRACT

Background: *Numerous studies show that seawater is the ecological niche of many microorganisms. Some microorganisms are pathogenic to humans. The purpose of this paper is to describe the biological agents and pathologies mentioned in the literature.*

Materials and methods: *This is a review of the literature from the Medline database. Keywords used were: "Bacteria" [MeSH]; "Bacteria/growth and development" [MeSH]; "Bacteria/pathogenicity" [MeSH]; "Viruses" [MeSH]; "Parasites/pathogenicity" [MeSH]; "Seawater" [MeSH]; "Mycoses" [MeSH]; "Eye Infections, Fungal" [MeSH]; "Skin Diseases, Infectious" [MeSH]; "Dermatitis" [MeSH]; "Seawater" [MeSH]. The articles were selected by two doctors from the abstracts, at first. The inclusion criteria were the treatment of a human pathology due to a microorganism contracted in contact with sea water. The exclusion criteria were not-to-treat human pathologies.*

Results: *The main microorganisms were bacteria:* S. aureus, Vibrio spp., Pseudomonas spp. *The main pathologies described were otorhinolaryngological, ophthalmological, digestive and dermatological infections. Some pathologies had a natural history that could have involved vital prognoses.*

Conclusions: *This analysis of the literature makes it possible to take stock of the pathogens and the main clinical pictures caused by the microorganisms living in seawater or tolerant to the sea water. This article can thus help the clinical physicians launched their microbiological diagnosis in front of this or that clinical picture. It also shows the recent evolution of microbial ecology in seawater, mainly in temperate zones. This constitutes an objective of epidemiological and environmental surveillance in the years to come.*

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Key words: "Seawater" [MeSH], "Viruses" [MeSH], "Bacteria" [MeSH], "Mycoses" [MeSH]

INTRODUCTION

Halophilic microorganisms belong to different taxonomic groups and to three microbiological domains: bacteria, archaea and eukaryota. The character they all have in common is their ability to multiply faster in the presence of NaCl [1, 2]. As for halotolerant microorganisms, these multiply better in the absence of salt, but are able to survive in low salt conditions and can be found in seawater and sewage. The concentrations of viruses or bacteria in seawater or sewage can be high [3] and represent a considerable reservoir of pathogens.

Moreover, the monitoring of aquatic environments is a public health concern. Various diseases may be caused in human populations depending on their contact with halophilic or halotolerant microorganisms. This is particularly the case for forms of virus-induced gastroenteritis. A recent study on this subject conducted in Latin America showed how concentrations of adenovirus, rotavirus and norovirus varied depending on rainfall [4]. A study in a French port also recently showed that seawater contamination fluctuates according to rainfall [5].

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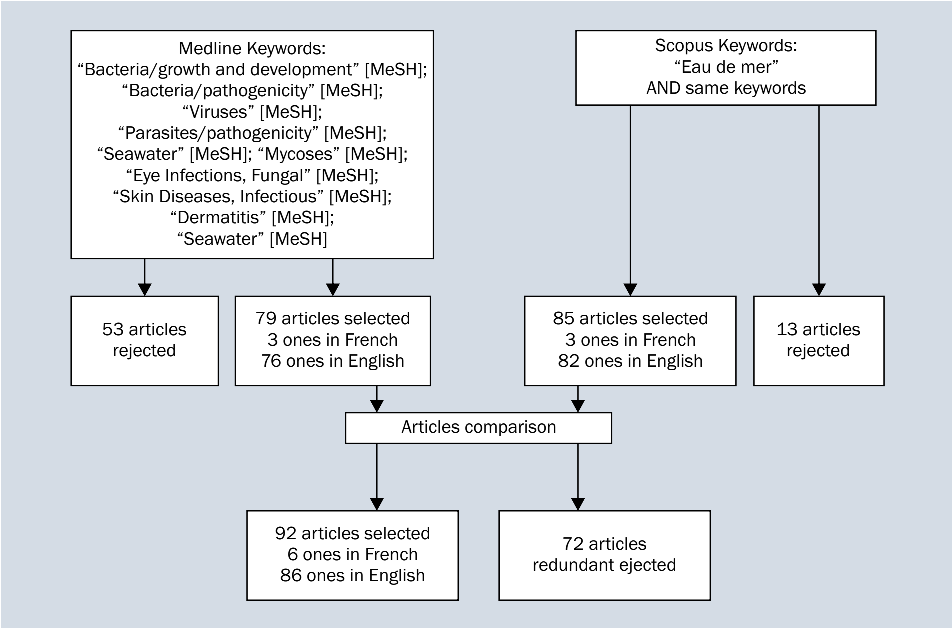

Figure 1. Flow chart

Fortunately, only a small proportion of halophilic and halotolerant microorganisms are pathogenic to man. Several studies have reported infections among people working in the maritime leisure industry [6, 7]. A recent prospective study showed that the main infection risks on the coast were gastroenteritis, skin damage, coughs, conjunctivitis or external otitis [8]. The risk was higher for bathers who spent longer in the water. During the Olympic Games in Rio in 2016, microbiological contamination in the bay was also a great cause of concern for the health of athletes in competitions on and in the water.

The purpose of this article is to make a synthesis of what we know about the halophilic and halotolerant microorganisms of surface seawater that are potentially pathogenic to man, and thus deduce the associated health risks. We will not address the pathogenicity of extremophile halophiles as we only cover microorganisms found in surface seawater and at shallow depths.

MATERIALS AND METHODS

The synthesis provided in this article is aimed at health risk assessment among people who are in contact with seawater or biological materials from the marine environment. We performed a literature search on the Medline database focusing on the period between 01/01/1990 and 31/05/2017. The search algorithms used the following keywords: "Bacteria/growth and development" [MeSH]; "Bacteria/pathogenicity" [MeSH]; "Viruses" [MeSH]; "Parasites/pathogenicity" [MeSH]; "Seawater" [MeSH]; "Mycoses" [MeSH]; "Eye Infections, Fungal" [MeSH]; "Skin Diseases, Infectious" [MeSH]; "Dermatitis" [MeSH]; "Seawater" [MeSH]. MeSH terms referring to extremophile microorganisms, such as "Halobacteriales" [MeSH] or "Halobacteriaceae" [MeSH], were excluded from the search.

The "human" filter was used in all searches.

Two doctors selected the articles based on their titles and abstracts. At this point, criteria were used to select the articles on survival in the marine environment of biological agents pathogenic to man, as well as clinical signs and their treatment. Therefore, we excluded articles that dealt with bacteria non-pathogenic to man, as well as articles that aimed to compare treatments, present in vitro experiments or evaluate environmental indicators (faecal indicators etc.). Freshwater studies were also omitted. Only articles in English and French were included in Figure 1.

RESULTS

In the cases covered by this study, the sources of exposure to biological risk were water and sediment. Although the most likely means of exposure discussed in the literature is the ingestion of contaminated sea products, activities in contaminated environments can also induce diseases [9–12]. However, swimming in ocean water, including ocean water at the beach that is not impacted by known point sources of pollution, is an increasing health concern, which has been covered only by a few studies [13]. People in contact with water through their work can be highly exposed to the associated biological risks. Indeed, the levels of contamination and exposure times can be much higher than the expected levels or those given in the regulations.

For example, divers working in port areas are highly vulnerable because the primary route of exposure is skin contact. Beside, sources of chemical and biological contamination are special: seawater and contaminated sediment [14].

HALOPHILIC AND HALOTOLERANT BACTERIA

Microbial ecology and survival

Results will be presented according to microbial type (bacteria etc.) rather than halophilic versus halotolerant character. In fact, no distinction was made between halophilic and halotolerant microorganisms in this study because we were principally interested in health risks.

The main bacteria are: *Escherichia coli, Salmonella sp., Proteus sp., V. cholerae, V. parahaemolyticus, P. aeruginosa, A. hydrophila, S. aureus* (Table 1) [10, 15]. Vibrios survive in both fresh and salt water [16–19]. There is a clear impact of global warming on the incidence of vibrios. Ocean temperature rise increases the prevalence of cholera cases [20, 21]. In Germany, thirteen cases were reported between 1993 and 2013 [22]. In Sweden and Finland, 89 cases were described during summer 2014 [23]. Non-cholera vibrios are also concerned by this phenomenon, including at high latitudes [21, 24], including lethal infections involving *V. vulnificus* [25]. A recent study showed the persistence of *E. coli,* enterococci and Bacteroidales HF183 in fresh and salt water for 3 to 5 days [26].

Other bacteria that can live in seawater include *H. pylori* [27, 28], and cyanobacteria. Konsisi et al. [27] compared the survival and the culturability of *H. pylori* in seawater and deep ground water, and grew a control in conventional *Brucella* broth liquid culture medium. Their results showed better culturability in deep ground water than in the control group ($p < 0.01$). These results have since been confirmed by another study [28]. Moreover, *H. pylori* seems capable of surviving in coastal freshwater, estuarine water and seawater [28]. From another perspective, some cyanobacteria (*Nodularia, Anabaenopsis, Lyngbya, Synechococcus* and *Trichodesmium*) can grow well at salinities close to those of seawater [29]. For cyanobacteria, climatic temperature is likely to enhance the magnitude and frequency of these events. For example, the cyanobacterium *Lyngbya majuscula* has a summer blooming period and releases dermatoxins, including lyngbyatoxin A and debromoaplysiatoxin, during this period. These toxins are known to cause dermatitis [30]. Finally, certain atypical bacteria have been reported to cause infections after contact with seawater. One such example is *M. marinum*, which is mainly found among aquarium hobbyists. Several articles describe infection of lesions by this pathogen following seawater exposure, which typically take the form of a granuloma [31].

Some bacteria can vary in concentration according to season and climatic data. For example, *Shewanella algae* and *Shewanella putrefaciens* increase in summer because there is more algal decomposition at this time [32].

Other halophilic or halotolerant bacteria can be harmful to man. The *Aeromonas* genus, for example, survives in the marine environment [33]. Studies have shown that *Aeromonas hydrophila* varies according to strain; as do its fixation capacities [34]. Campylobacteria, mainly *Campylobacter jejuni*, were found in 12% of bathing waters in a study in Finland [35].

Incidences of *Staphylococcus aureus* and its methicillin-resistant strains (MRSA) have risen worldwide, and thus increased understanding of the routes of human exposure [36]. One approach to examining this question is to analyse beach sand and seawater. Mohammed et al. [37] studied the survival of non-enteric pathogens in sand, investigating the factors affecting the survival and distribution of *S. aureus* and *P. aeruginosa*. Their results show that there is greater *S. aureus* and *P. aeruginosa* survival and proliferation in sterile beach sand than in seawater. Sand particles between 850 μm and 2 mm constituted the major micro-niche. A study in California detected *S. aureus* in samples of seawater (59%) and sand (53%). The significant explanatory variables for *S. aureus* in seawater were water temperature, or presence of enterococci in the seawater, and the number of swimmers [36].

Clinical findings

Certain pathogenic halophilic bacteria cause digestive infections if contamination occurs by ingestion. If contamination occurs through contact with the integuments, infection can be dermatologic, otologic or ophthalmologic [6, 10, 15, 37, 38]. In addition, *H. pylori* can infect the human stomach through ingestion of water [27]. Some bacteria are toxic [39]. For example, toxic cyanobacteria cause health problems [29, 39]. Several articles have covered toxin analysis, particularly in recreational areas, using methods such as ELISA, high-performance liquid chromatography and liquid chromatography-mass spectrometry [39, 40].

A few cases of human spondylodiscitis caused by *Shewanella algae* have been described recently [32, 41]. In these cases, the portal of entry was probably a cutaneous lesion on the leg that was exposed to seawater. A needle biopsy specimen from the vertebral disk was necessary to identify *S. algae* [41]. Other articles reported osteo-articular infections, arthritis and osteomyelitis by *S. algae* [42, 43]. One case of acute exudative tonsillitis was also described [44]. Two other patients with lower leg ulcers had bacteraemia [45]. In Denmark, *S. putrefaciens* and *S. algae* can be isolated from seawater with a salinity of 15–20% [46].

If people in contact with water also have skin lesions, these may be susceptible to infection or superinfection. In such cases, infections by rarer biological agents and more serious infections have been observed. Escudero et al. [47]

Table 1. Halophilic or halotolerant bacteria and pathologies

Gram	Genre	Species	Pathologies
Gram-negative bacilli	*Enterobacteriaceae*	*Escherichia coli* [10, 13, 15, 57]	Gastroenteritis
		Salmonella sp. [10, 15] *S. typhi* [82]	Gastroenteritis
	Vibrio	*V. cholerae* [10, 15, 69]	Gastroenteritis Dermohypodermitis [69]
		V. parahaemolyticus [69, 70]	Gastroenteritis Wound infections [71] Dermohypodermitis [69]
		V. alginolyticus [19, 69]	Gastroenteritis Wound infections
		V. vulnificus [21–25, 69, 72, 73]	Gastroenteritis Wound infections Dermohypodermitis
		V. alginolyticus	Cutaneous ulcer [47] Necrotizing fasciitis [50]
	Pseudomonas	*P. aeruginosa* [10, 15, 69]	Gastroenteritis Skin disease Septicaemia Pneumonia Urinary tract infection Ear infection Ophthalmic infection
	Aeromonas	*A. hydrophila* [10, 15, 34, 69]	Gastroenteritis Dermohypodermitis [69]
	Clostridium	*C. perfringens* [13, 37]	Gastroenteritis Skin disease Dermohypodermitis [69]
	H. pylori	[74, 75]	Gastric disease
Rod-shaped Gram-negative	*Shewanella*	*S. algae*	Spondylodiscitis [41, 46] Acute exudative tonsillitis [44] Arthritis [42] Osteomyelitis [43) Ear infection [76] Bacteraemia [45, 76] Skin disease [77, 78] Dermohypodermitis [Park 2009]
		S. putrefaciens	Skin disease [77–79] Dermohypodermitis [80] Cerebral abscess [81] Bacteraemia [82]
Gram-positive cocci	*Streptococci*	*Streptococcus spp.* [69]	Gastroenteritis Skin disease Dermohypodermitis Ear infection Ophthalmic infection
	Staphylococci	*S. aureus* [10, 13, 15, 36, 37, 69, 83]	Gastroenteritis Skin disease dermohypodermitis Ear infection Ophthalmic infection
	Mycobacteria	*M. marinum* [79, 86]	Skin disease

Table 2. Halophilic or halotolerant viruses and pathologies

Gender	Species	Pathologies
Enterovirus [13, 82, 85]	Poliovirus I and Poliovirus III	Poliomyelitis [57, 58, 87]
	Coxsackie A and Coxsackie B	Gastroenteritis [3, 88, 89]
	Echovirus	Gastroenteritis [88, 89]
Caliciviruses	Norwalk virus	Gastroenteritis [55, 57, 87, 90, 91]
	Human Caliciviruses	Gastroenteritis [56]
Rotavirus [82]		Gastroenteritis [4, 57, 58]
Noroviruses		Gastroenteritis [4, 57, 59, 60, 63]
Adenovirus		Gastroenteritis Ophthalmic infection [4, 6, 58]
Hepatovirus	Hepatitis A virus	Hepatitis [13, 57–60, 84, 85]
	Hepatitis E virus	Hepatitis [13, 57–60, 84, 85]

Table 3. Halophilic or halotolerant parasites and fungi and pathologies

Organism		Principal pathologies
Acanthamoeba		Ophthalmic infection [6]
*Giardia**	*G. intestinalis*	Gastroenteritis [13, 92, 93]
*Cryptosporidium**	*C. hominis*	Gastroenteritis [13, 93, 94]
Microsporidian spores	*Enterocytozoon bieneusi*	Gastroenteritis [93, 94]
	Encephalitozoon intestinalis	Gastroenteritis [93, 94]

*The levels of *Cryptosporidium* spp. and *Giardia* spp. in samples were generally below the detection limit.

described an infection and the formation of a skin ulcer caused by *Vibrio alginolyticus* in a patient who had had radio-dermatitis 15 years earlier. The infection developed after the patient had gone to the beach during the month of August. As infections are generally more frequent on damaged skin, preexisting dermatoses should be treated before contact with seawater [48, 49].

Finally, a decrease in a person's general level of health can increase their susceptibility to infection. Thus, Gomez et al. [50] described a case of necrotising fasciitis in an immunocompromised patient following corticoid treatment. The patient was a 48-year-old woman with history of asthma. She was treated with steroids. She was injured on coral while she was bathing in Caribbean Sea off Colombia. This injury was the starting point of a necrotising fasciitis because of *Vibrio alginolyticus*.

VIRUSES

Nearly 100 human viruses are known to survive in marine waters (Table 2) [51, 52]. Enteric viruses can often be detected in marine waters in the absence of total and faecal coliforms. Viruses have been detected in almost 50% of coastal water samples [53]. Avian influenza viruses can survive in seawater [54].

Caliciviruses survive more than 14 days when placed directly into artificial seawater and held at 15°C [55], and feline caliciviruses, employed as a model for the measurement of human calicivirus stability in marine water, are themselves stable in marine water [56]. Several studies showed that 55% to 64.2% of coastal water samples were positive for adenovirus; 8.3% to 51.9% for hepatitis A virus (HAV); 12.5% to 19% for rotavirus; 7.5% for noroviruses and 3% for poliovirus in Brazil and Mexico [57–59]. These results highlight the problem of sewage discharge into coastal waters. A study in Portugal showed that HAV and norovirus group I were detected in 95% and 27% of water samples, respectively, despite European regulations [60]. Additionally, a study on European recreational water areas detected adenoviruses in 36.4% of samples, and noroviruses in 9.4% (with 3.5% for group I and 6.2% for group II). In the United States, between 0.7% and 25.5% of samples were found positive for adenovirus and norovirus [61].

Noroviruses are the principal agents of gastroenteritis following consumption of bivalve molluscs [62]. In vitro, human norovirus RNA persisted in seawater for 14 days following contamination [63].

PARASITES AND FUNGI (TABLE 3)

Few human pathogenic parasites can survive in salty water. The main ones that can are: *Acanthamoeba* (Table 4). Several studies have shown the presence of *Giardia* and *Cryptosporidium* in seawater [13, 64, 65].

During the summer months, samples of recreational bathing waters were tested for human-virulent microsporidian spores. *Enterocytozoon bieneusi* spores were detected in 59% of samples, and *Encephalitozoon intestinalis* spores were concomitant in a sample from a single weekend; the overall prevalence was 43%. Water turbidity and the concentration of waterborne spores were significantly correlated with bather density, with p values of < 0.001 and < 0.01, respectively.

Infectious diseases can therefore affect people bathing or participating in water sports that start from/end at the beach; direct skin contact with the sand being the main risk factor [66].

A study by Graczyk et al. [67] showed that bathing in public waters can result in exposure to potentially viable microsporidian spores and that body-contact recreation in potable water can play a role in the epidemiology of microsporidiosis. The study showed that the resuspension of bottom sediments caused by bathers, and their direct microbial input, resulted in elevated levels of *Cryptosporidium parvum* oocysts, *Giardia lamblia* cysts, and microsporidian spores, particularly *Enterocytozoon bieneusi*, in recreational beach water on days deemed acceptable for bathing with regard to faecal bacteria standards.

Contamination of coastal waters depends on climatic and meteorological conditions. For water at beaches, Sunderland et al. [64] showed that the level of *Cryptosporidium parvum* oocysts and *Giardia lamblia* depended on the number of bathers. Over several weeks, significant differences were shown depending on levels of beach use.

HEALTH RISKS

To summarise, the infections recorded in the literature are gastroenteritis, respiratory infections, skin infections, conjunctivitis and external ear infections [68]. Some symptoms can develop independently; in particular, some patients can have sepsis without clinical signs.

Table 4. Main pathologies and matching halophilic pathogens

Principal pathologies	Micro-organisms	
Gastro-enteritis	Bacteria	*Escherichia coli* *Salmonella sp.* *V. cholerae* and others *Vibrio* *P. aeruginosa* *A. hydrophila* *C. perfringens* *Streptococci* *S. aureus*
	Viruses	Coxsackie A and Coxsackie B Echovirus Norwalk virus Human Caliciviruses Rotavirus Noroviruses Adenovirus
	Parasites	*Giardia* *Cryptosporidium* Microsporidian spores
Skin disease	Bacteria	*Pseudomonas* *Shewanella algae* and *putrefaciens* *Streptococci* *S. aureus* *M. marinum* *Cyanobacteria*
	Viruses	–
	Parasites	–
Ophthalmic infection	Bacteria	*Pseudomonas* *Shewanella* *Streptococci* *S. aureus*
	Viruses	Adenovirus
	Parasites	*Acanthamoeba*
Ear infection	Bacteria	*Pseudomonas* *Streptococci* *S. aureus*
	Viruses	–
	Parasites	–

DISCUSSION

This article brings together the microbiological data on the pathogenicity of halophilic and halotolerant microorganisms to humans. It is a summary that can therefore help doctors to improve the way they care for patients who are sea users, including marine professionals (fishers, sailors in the merchant navy etc.), leisure boaters and bathers. It can also be useful for doctors treating sportspersons practicing new water sports. In particular, certain sports such as jet ski and kitesurf are more likely to lead to traumatic injuries that cause lesions, which can become infected by certain microorganisms. It is important for doctors to take these particular data into account so that they can adapt therapy when applicable.

This article has several limitations, however. We chose to inventory risks of infection related to seawater but have not covered intoxication risks linked to bacteria and other microorganisms in seawater. In particular, we did not describe all the risks, acute or chronic, associated with cyanobacteria; this subject deserves a detailed dedicated study of its own [95]. Nor did we study the infection risks of seafood consumption. These include shellfish, for example, which can be contaminated by various viruses [96].

Another limitation could be that we have not distinguished between halophilic and halotolerant microorganisms. We made this choice as there is no clinical or therapeutic interest in knowing whether a germ is halophilic or halotolerant. This question is mainly of interest to environmental microbiologists, for example to describe the different habitats or molecular mechanisms of adaption of these microorganisms, or people working in biotechnology industries who want to choose a species capable of multiplying at a particular salt concentration required for a fabrication process [2, 97].

There are few articles on pathogenic halophilic fungi. Mycoses are nevertheless common among sailors [98, 99]. Several factors can explain this high incidence: overcrowding, maceration, humidity, heat, lack of hygiene, etc. These diseases are not specifically caused by halophilic organisms, but are worsened in the marine environment. Submariners, although they are not in contact with seawater in their submarines, are also affected by this public health problem. In a study on Russian submariners, the prevalence of mycoses was 41.2%, mainly *Candida albicans* (80.7%) and *guilliermondii* (11.6%), and *Trichophyton interdigitale* (7.7%) [100]. Then there is the question of halophilic fungi. Several articles have shown that some pathogenic fungi can survive in seawater. Fayer thus showed that spores could be stored in seawater at 10°C for 1 to 12 weeks [101]. Anderson [102] showed that *Trichophyton mentagrophytes*, *Trichosporon cutaneum*, *Candida albicans*, and *Microsporum gypseum* can survive 52 weeks in seawater at 20°C to 35°C and 6% to 50% salinity. However, these are experimental studies so that do not provide clinical data.

The question should also be asked of whether, under natural conditions, pathogenic species can survive and infect bathers. Data from the literature show that some marine microorganisms secrete toxins as a defence against certain fungal species [103–106]. El Amraoui et al. [104, 105] tested the anti-fungal capacities of 34 marine microorganisms against four fungi and found that 13 (38%) of the strains showed antifungal activity. These were mainly bacteria: *Acinetobacter*, *Aeromonas, Alcaligenes, Bacillus, Chromobacterium, Enterococcus*, *Pantoea,* and *Pseudomonas.* Some sponges also show this kind of activity [107]. Dhayanithi et al. [107] showed that *Sigmadocia carnosa* has active metabolites against four dermatophytic fungi: *Trichophyton mentagrophytes*, *Trichophyton rubrum*, *Epidermophyton floccosum* and *Microsporum gypseum*.

The fact that many marine microorganisms secrete fungicidal molecules suggests that marine fungi are numerous. New culture and molecular biology techniques will perhaps allow us to discover more halophilic pathogenic fungi in years to come.

The purpose of this article is to better inform doctors about primary prevention. We have inventoried the main microorganisms according to each large class of infectious diseases shown by people in contact with seawater. It therefore provides a microbiological orientation useful for doctors treating patients who have such diseases. This is particularly the case for empirically based antibiotic therapy.

Preventive measures can also take different forms. For example, beach water is regularly tested and the users informed of the results. However, these measures need to be adapted according to the country and hydrographic data. In fact, we know that some water contamination is caused by the persistence of microorganisms in sand, which implies that the risks differ among seas and tidal conditions. The risk of infection linked to seawater is a major world health challenge. In 2003, an estimated 120 million people contracted gastroenteritis and 50 million developed a severe respiratory infection after having swum or immersed themselves in seawater. The impact on health was therefore “estimated to be about 3 million ‘disability-adjusted life years’ (DALY)/year, with an estimated economic loss of some 12 billion dollars per year” [108]. It would also be useful to conduct microbiological analyses according to both the season and major meteorological parameters such as rainfall and events such as flooding. These events can considerably alter the microbial ecology of a given marine environment [5, 109].

Prevention is also accomplished through the improvement of health surveillance. Increased knowledge on microbiology seems essential in a world where oceans change their composition (particularly salinity) and temperature. Epidemiological monitoring is one of the most important means of combating emerging diseases. Cholera has appeared in northern waters and the prevalence of other diseases has changed in recent years. Thus, the most common viral hepatitis in France is no longer hepatitis A, but hepatitis E [85]. No cases of hepatitis E have yet been described in sailors. This is why we must remain vigilant.

CONCLUSIONS

This paper provides a review of halophilic and halotolerant microorganisms (bacterial, viral, parasitic and fungal), indicating the diseases that can be caused by these microorganisms.

In recent years, climate change has altered disease distribution in the world. Certain microorganisms are developing increasingly in the north. This alters the risks for sea users, whether professional sailors, recreational boaters or bathers. Doctors treating these people need to take into account the changes in microbial ecology for diagnoses and therapy orientation. This article will be used by physicians to better understand, diagnose, and prevent marine diseases.

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