

# Anti-Biofouling Defence Mechanism of Basibionts (A Chemical Warfare) - A Critical Review

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## Abstract

The fouling process is an ecologically complex web of interactions between basibionts e.g., corals, surface-colonizing microbes e.g., bacteria, and fouling biota e.g., *Balanus species* which are all mediated by chemical signalling. Sessile invertebrates, such as soft corals, sponges and sea cucumbers, evolved in an intense competitive milieu for space, light and nutrients, therefore they have developed chemical defence mechanism by producing secondary metabolites e.g., Terpenes to ward off bio-foulers and maintain clean body surfaces. The settlement of surface-colonizing organisms, commonly referred to as bio-fouling organisms, occurs naturally in a turbulent environment, yet the effects of waterborne versus surface-adsorbed chemical defences have not been compared in flow, therefore limiting our understanding of how they respond to toxic surfaces of the basibionts. Here, we reviewed the evidence that basibionts chemically inhibit the propagules of fouling organisms under natural conditions, and that chemosensory mechanisms may allow the larvae of bio-fouling animals to detect and avoid settling on chemically protected basibionts.

**Keywords:** Fouling biota; Basibionts; Settlement; Chemical signalling; Toxic surfaces

## Introduction

Basibionts are substrate or benthic organisms which are the hosts to epibionts or bio-foulers. Corals and sponges are the most studied groups of benthic invertebrates in marine chemical ecology due to their abundance and distribution in all seas [1,2]. Several studies have been conducted by the benthic ecologists and chemists to unravel the mechanisms of chemical defence of the basibionts which protect their surfaces against fouling from epibiotic association. Many marine invertebrates such as soft corals and sea cucumbers are sessile i.e., steadily attached to the sea bottom or with low movement, thus vulnerable either to predation and threat from a rich surrounding microbiota with pathogenic potential. One of the most important challenges for the benthic organisms is to combat the problems of biofouling. 'Biofouling' is the colonisation of submerged surfaces by unwanted organisms such as bacteria, barnacles, algae, etc and has detrimental effects on shipping and leisure vessels, heat exchangers, oceanographic sensors and mariculture, with considerable ecological and economic consequences [3]. Soft corals and sea cucumbers are under intense competitive pressure for space, light, and nutrients. Fouling can have severely deleterious effects on benthic organisms, such as inhibition of photosynthesis, blockage of filter feeding, and elevated risk of mechanical dislodgement or predation. It is not surprising that they have developed a range of chemical defences to ensure their survival. Biofouling has been shown to be a sequential process [4], one stage of succession being conducive to the onset of the next [5]. Although these mechanisms are somewhat different for micro- and macro-organisms the sequence of events follows a similar pattern (Figure 1): settlement, attachment, development and growth of foulers such as bacteria, protists, barnacles, bivalves, hydroids, sedentary polychaetes, bryozoans, anemones, tunicates, diatoms, as well as green, brown and red algae [6-10]. Fouling is described as an on-going process which has no true end, as even a mature fouling community will undergo changes in composition due to season, disturbance, predation, and other biological and abiotic influences. As said earlier, soft corals, sponges, sea cucumbers live in close association with microorganisms like bacteria and other bio-foulers like barnacles and their body surfaces are inevitably colonized by these

epibionts; while some of them harbour microorganisms within their digestive tracts or even within tissues and cells. Such interactions are complex and reach from harmful diseases to symbioses of mutual benefit [11]. Associated microorganisms have recently been shown to be involved in the synthesis of numerous metabolites [12]. Numerous studies demonstrate secondary metabolite production by symbionts such as the synthesis of the bicyclic glycopeptide theopalauamide by an associated delta-proteobacterium in the sponge, *Theonella swinhoei* [13], the synthesis of bryostatin by bacterial symbionts in the bryozoan, *Bugula neritina* [14], or the antimicrobial activity of different bacterial strains isolated from the sponges, *Aplysina aerophoba* and *A. cavernicola* [15]. Bio-foulers like some microbes play a double role in chemical interactions with higher organisms like the corals. They can be harmful and are repelled by chemical defences or they may be useful symbionts for their hosts by providing protection and camouflage against predators hunting by visual or chemical cues [16,17]. Soft corals and sea cucumbers have evolved mechanisms that enable them to distinguish between beneficial and detrimental biofoulers. Secondary metabolites act as a controlling factor in this host-biofouler interaction. They are used as a defence strategy against unwanted colonization (infection) by bio-foulers. These sessile invertebrates, soft corals, sponges, and sea cucumbers (Figure 2), produce an astonishing variety of anti-biofouling compounds (structures in Figure 3) [18], which help them to ward off surface colonization [19,20].

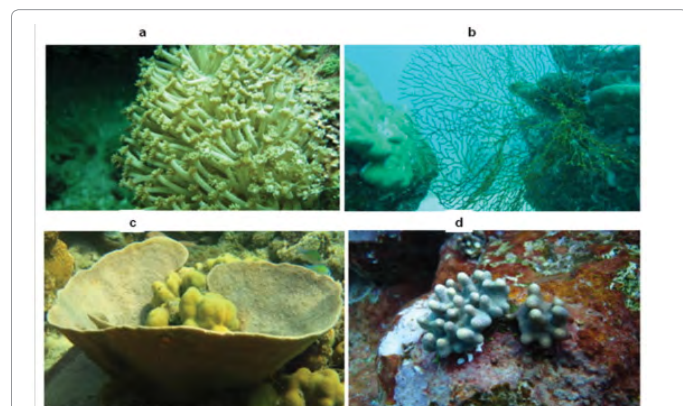
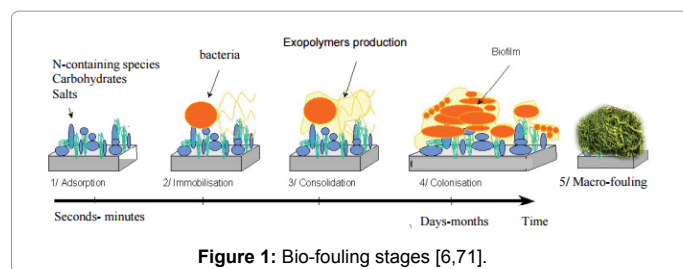
The aim and objective of this review is to focus on chemical defence mechanisms of some hard and soft corals, sponges and sea cucumbers against multiple fouling organisms or epibionts in the field.

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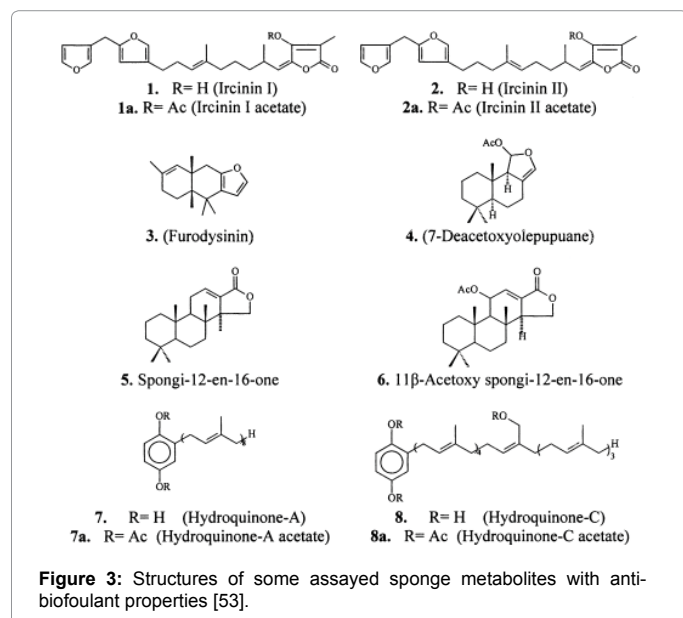
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**Figure 2: Examples of marine invertebrate groups commonly reported in the literature for studying production of anti-fouling repellent substances. a: Coral; b: Gorgonian; c: Sponge; d: Soft coral. (Underwater images from the Red Sea) [72].**



## Chemical Defensive Mechanism against Bio-Fouling

Secondary metabolites are widespread among benthic invertebrates and understanding their functional roles in the producing organism has been under intense study in recent times. The hypothesis that sessile or slow-moving organisms, without obvious escape mechanisms and physical protection, are likely to be chemically defended has recently been explored with greater frequency in the marine environment.

For any long-lived sessile benthic organisms like soft corals and

sea cucumbers, bio-fouling and epibiosis must either be tolerated or overcome due to the setbacks associated with a colonized surface, these include; inhibition of photosynthesis, blockage of filter feeding apparatus, and increased risk of mechanical dislodgement or predation [21]. In response to this, a variety of chemical compounds are secreted by benthic invertebrates like soft corals, sea cucumbers, sponges to prevent surface fouling [22]. Some of these compounds prevent settlement much more effectively than organotin compounds and at the same time are far less toxic [23]. Chemical-based settlement inhibition against bacteria and other bio-foulers has been reported in sponges [24-30], Ascidians [24,31,32] and Cnidarians [30,33-36] and Bryozoans [23,37].

Because they lack physical defences, soft-bodied sessile invertebrates such as soft corals often use a refined chemical weapon as antifouling agents such as terpenoids, steroids, acetogenins, alkaloids, and polyphenolics [38]. These compounds can act enzymatically by dissolving the adhesives, interfering with the metabolism of the fouling organisms (e.g., nervous pathway interference), inhibiting the attachment, metamorphosis or growth, promoting negative chemotaxis, altering the surface of the organisms and as repellents [39-41]. Octocorals (class Anthozoa, subclass Octocorallia, and order Alcyonacea, family Alcyoniidae) were one of the first benthic invertebrate groups that were systematically screened for secondary metabolites (Tursch, 1976). These compounds, especially cembranoid diterpenes [42], have a function in chemical defence, in competition for space (allelopathy) and against fouling [43-46]. These diterpenes e.g., from *Sinularia flexibilis*, although lipophilic, are highly soluble in seawater and as anti-fouling agents are selectively absorbed onto bio-membranes of fouling organisms. Triterpene glycosides from two sponges, *Erylus formosus* and *Ectyoplasia ferox*, were tested for a suite of activities including predator deterrence, bacterial attachment, fouling, and overgrowth by competitors. The results showed a strong inhibition of fouling by invertebrates and algae over a 27-day period [47]. Soft corals may chemically affect the larvae of other corals, interactions at the interface of antifouling and allelopathy. Scleractinian coral recruitment was depressed in a current-dependent directional manner around the soft corals *Sinularia flexibilis* and *Sarcophyton glaucum*, and settlement did not occur on plates containing an extract of *S. flexibilis* [48]. The diterpenes flexibilide, dihydroflexibilide, and sinulariide from *S. flexibilis* were toxic to fertilized eggs of the hard corals *Montipora digitata* and *Acropora tenuis* during the first 24 hr [49]. The Atlantic species *Eudistoma olivaceum* produces a range of over 20 alkaloids termed eudistomins [50]. The antilarval activity of these compounds was traced to a pair of isomeric carboline alkaloids, eudistomins G and H. Both of these compounds from the ascidian were found to inhibit settlement of *Bugula neritina* larvae at 2 µg per square cm due to their toxicity in bioassay trials [51]. Secondary metabolites, such as 1-methyladenine from *Aplysilla glacialis* [25], extracts from *Crambe crambe* [26], as well as aethionin and homo-aethionin from *Aplysina fistularis* [52] showed strong antibacterial and bryozoan larval properties. *Dendronephthya spp.*, a Cnidarian, was also reported to contain horamine (*N*-methyl-4-picolinic acid) that significantly inhibited growth of the co-occurring benthic diatom *Navicula salinicola* [30,33]. The antifouling activity of a series of extracts and secondary metabolites, such as bromopyrrole or diterpene alkaloids, from the epibiont-free Mediterranean sponges, *Ircinia oros spinosula*, *Cacospongia scalaris*, *Dysidea sp.*, and *Hippospongia communis* was investigated by Hellio et al. [53]. A number of the tested metabolites had anti-settlement activity when tested against barnacle, *Balanus amphitrite*, cyprids. The effect of sponge extracts and metabolites on

the settlement of barnacles was tested by Hellio et al. using cyprids of *Balanus amphitrite*. The results of the effectiveness of the sponge extracts or metabolites in inhibiting *B. amphitrite* settlement is presented in Table 1 and Figure 4.

In a study reported by Limnamol et al. [54], thirty six species of sponges collected from the Gulf of Mannar, India, were tested for their inhibitory effect on fouling bacterial strains and cyprids of *Balanus amphitrite*. The results showed that *Fasciospongia cavernosa* and *Petrosia nigricans* had a high significant inhibitory or anti-settlement activity against the fouling bacteria and *Istrochota baculifera* larvae.

The experiment carried out by Yang et al. [55] to test for the anti-fouling property of two- compound extracts (10b-formamidokalihinol-A and kalihinol A) from sponge, *Acanthella cavernosa*, against the bacterial and larval settlement of a major fouling polychaete, *Hydroides elegans*. The results showed that both compounds inhibited the growth of bacteria isolated from the natural environment whereas kalihinol A suppressed larval settlement due to modification of bacterial communities on their surfaces which has influence on larval settlement of fouling organism (Figures 5 and 6).

Blihoghe et al. [56] reported that agelasine derivatives, from sponges and soft corals, inhibited settling of larvae of *Balanus improvisus* in an anti-fouling bioassay as well as the growth of planktonic forms of biofilm forming bacteria, *Staphylococcus epidermidis*.

Several studies conducted have shown that soft corals can yield large quantities of promising antifouling metabolites [57]. Chambers et al. [58] reported that 17.95% of potential antifouling natural compounds are from cnidarians (e.g., soft coral). One of the most promising natural antifouling agent identified so far is an isogosterone isolated from an unspecified *Dendronephthya* [37]. Lai et al. [59] evaluated the anti-fouling property of diterpenoids, designated as sinulariols A-S, from Chinese soft coral *Sinularia rigida* on *Balanus species* and concluded that they inhibited the larval settlement of both *Balanus amphitrite* and *B. neritina*. Pereira et al. [60] and Epifaino et al. [61] showed that the diterpene 11 $\beta$ , 12 $\beta$ -epoxypukalide extract from *Phyllogorgia dilatata*, an octocoral, displayed antifouling property when tested on *Perna perna*

and barnacles. Roper et al. [62] revealed that haliclonyclamine A and halaminol A isolated from the sponge, *Haliclona sp.*, have similar effects on sponge, polychaete, gastropod, and bryozoan larvae by inhibiting their settlement and metamorphosis. Qi et al. [63] demonstrated that subergorgic acid, isolated from a gorgonian, inhibited settlement of larvae of *B. amphitrite* and *B. neritina*, with EC<sub>50</sub> values of 1.2 and 3.2  $\mu$ g/mL respectively and LC<sub>50</sub> values of >200  $\mu$ g/mL. Peters et al. [64] showed that two bromophysostigmines, isolated from the bryozoan, *Flustra foliacea*, inhibited bacterial quorum sensing (QS) and the growth of bacteria, suggesting the presence of potential anti-fouling compounds.

## Discussion and Conclusion

Marine invertebrates are one of the major groups of biological organisms (Porifera, Cnidaria, Mollusca, Arthropoda, Echinodermata, etc.) that are significant for their source of a number of natural products and secondary metabolites with anti-biofoulant properties.

It is reported that the secondary metabolites of some species of basibionts can vary quantitatively and qualitatively, depending on the biogeographical location [65], while other species have similar compositions of these metabolites in different habitats [66]. Fusetani proposed that these organisms secrete chemicals that prevent larvae of other marine organisms from settling and growing on them [67]. From the data presented here, it can be concluded that extracts of the various basibionts control a number of epibionts and bio-foulers from settling on their surfaces. Walls et al. [68] and Shellenberger and Ross [69], reported a negative correlation between the presence of secondary metabolites, the antibacterial activity of the extracts and a reduction of fouling, which might indicate an antifouling function for secondary metabolites. Investigations on the Caribbean sponges, *Erylus formosa* and *Ectyoplasia ferox*, showed that triterpene glycosides has multiple ecological functions to deter predation, microbial attachment, and fouling of invertebrates and algae [47,70]. It was found that the metabolites are apparently restricted to the sponge surface and the biological effect is through direct contact with the sponge rather than by water borne interactions. These results support the hypothesis that

Group I (Active and toxic metabolites/extracts)	LC50 (ppm)		EC (ppm)
Ircinin I&II	4.7		5.0
Ircinin I&II acetates	4.9		5.0
Furodysin	18.1		5.0
Ircinin oros CH <sub>2</sub> Cl <sub>2</sub> extract	21.7		50.0
7-Deacetoxyolepupane	106.2		100.0
Dysidea sp. CH <sub>2</sub> Cl <sub>2</sub> extract	52.5		65.9
Group II (Non-active and nontoxic metabolites/extracts)	%Survival	%Settlement	Concentration ( $\mu$ g/mL)
Spongi-12-en-16-one	100	60.3	100
Hydroquinone A	100	59.4	100
Hydroquinone C	100	57.3	100
Fasciculatin	100	58.0	100
Dysidea sp. aqueous extract	100	59.1	100
11 $\beta$ -Acetoxyspongi-12-en-16-one	100	53.5	100
Group III (Active and nontoxic metabolites/extracts)	%Survival	%Settlement	Concentration ( $\mu$ g/mL)
Euryfuran	100	24.7	100
Hydroquinone A-acetate	100	19.9	100
Dihydrofurospingin II	100	11.2	100
Hydroquinone C-acetate	100	0.0	10
Dysidea sp. alcohol extract	100	0.0	25

Metabolites/extracts are classified according to their activity on inhibition of settlement. In group I, results are expressed as effective concentration for 0% settlement (EC) and concentration including 50% lethality (LC<sub>50</sub>). For groups II and III, results are expressed as percentage of survival and of settlement for the reported concentrations.

**Table 1:** Settlement inhibition activity against *Balanus amphitrite* cyprids [53].

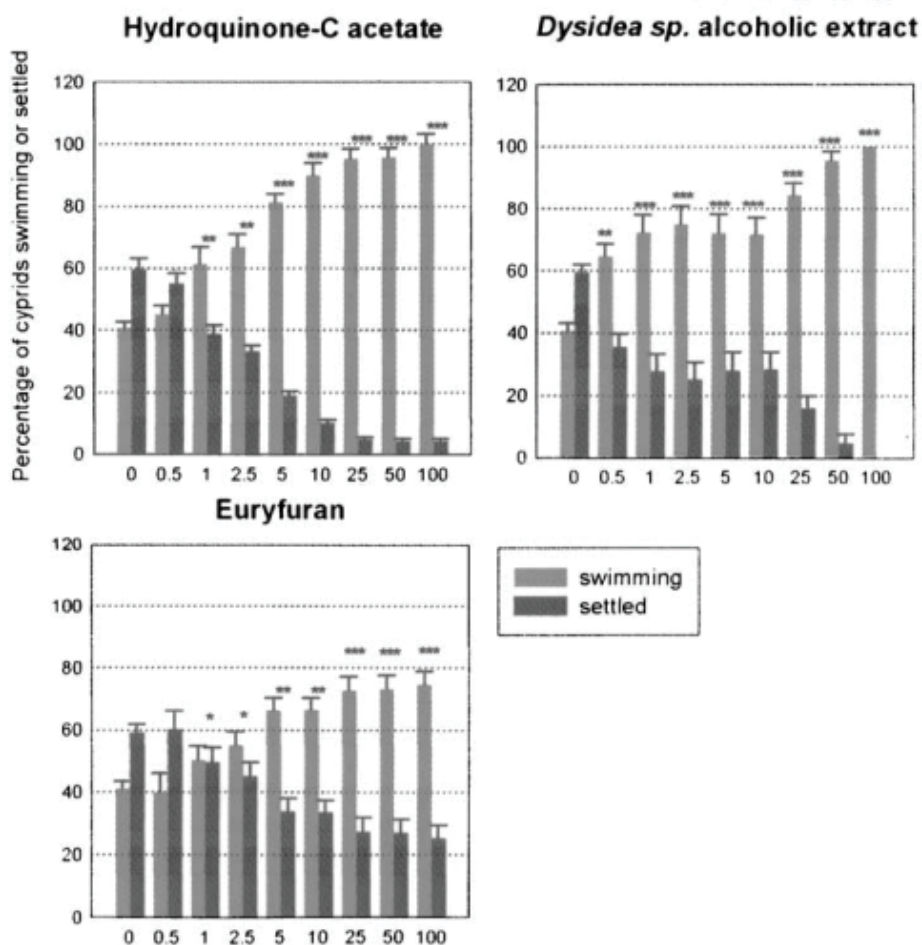


Figure 4: Effect of the most active nontoxic metabolites/extracts (0 to 100 g/mL) on *B. amphitrite* cyprid settlement. Results are expressed as percentage settled ( $\pm$  SEM) and percentage swimming ( $\pm$  SEM). Results significantly different from the control, \*P<0.05; \*\*P<0.001; \*\*\*P<0.001 [53].

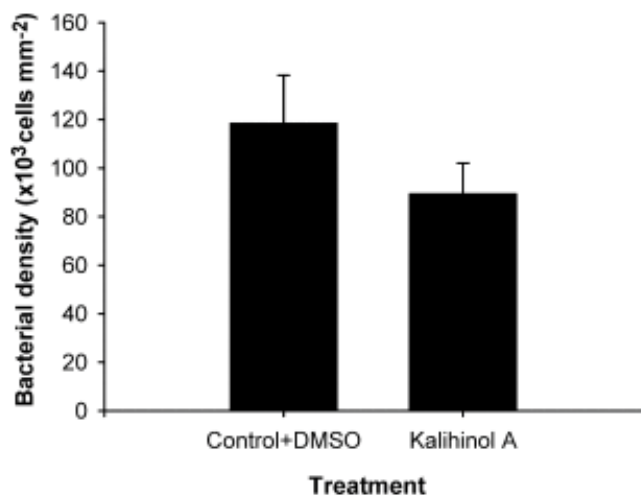


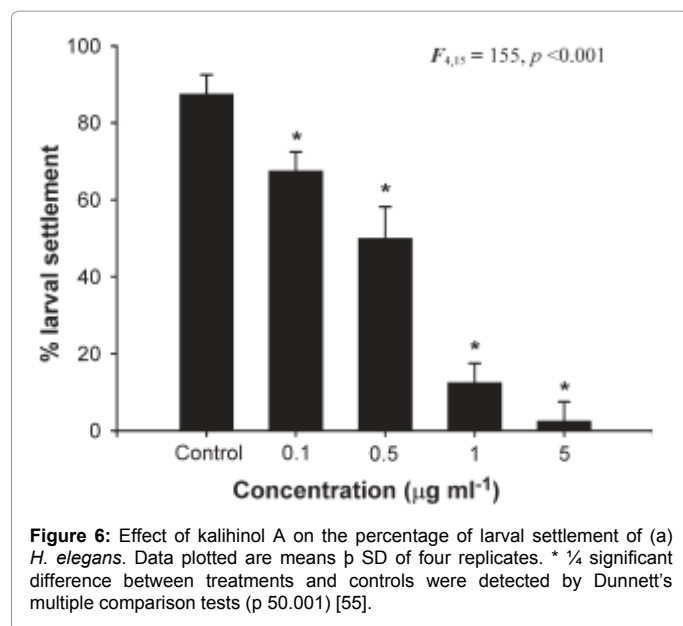
Figure 5: Bacterial density on the surface of Phytagel1 embedded with kalihinol A and the control containing DMSO (n ¼ 3). The Phytagel1 were exposed to flow-through natural seawater for 3 d at 208°C in March 2005 [56]. DMSO: Dimethyl sulfoxide.

invertebrate metabolites are involved in the regulation of microbial and other bio-fouler distributions in the marine environment, and may act as a chemical defence aimed at controlling surface colonization. Therefore, it can now be concluded that surfaces of marine invertebrates, e.g., sponges, soft corals, are usually remarkably free of fouling organisms, supporting the assumption that this is achieved by secretion of anti-fouling compounds [71,72].

A lot of antifouling compounds have been isolated and reported from marine sponges, sea anemones, soft coral, etc but their molecular structures are too intricate to be artificially synthesized. Better understanding of the natural function of these secondary metabolites will to develop new strategies for the correct management and protection of these potentially important natural resources, the basibionts, for the future and find new biotechnological applications for these products in our day-to-day lives. Exploiting these marine biotas could lead to scarce supply of anti-fouling compounds widely used by many industries such as aquaculture, pharmaceutical and shipping.

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## References

- Jackson JBC (1977) Competition on marine hard substrata: the adaptive significance of solitary and colonial strategies. *Am Nat* 3: 743-767.
- Uriz MJ, Rosell D and Martín D (1992) The sponge population of the Cabrera archipelago (Balearic Islands): characteristics, distribution, and abundance of the most representative species. *Mar Ecol* 13: 101-117.
- Vimala R (2016) Marine organisms: A potential source of natural antifouling metabolites. *International Journal of ChemTech Research* 9: 208-217.
- Raillkin AI (2004) Marine biofouling. Colonization processes and defenses.
- Connell JH and Slatyer RO (1977) Mechanisms of succession in natural communities and their role in community stability and organization. *American Naturalist* 11: 1119-1144.
- Christensen BE and Characklis WG (1990) Physical and chemical properties of biofilms. In Characklis WG and Marshall KC (eds). *Biofilms*, New York: J Wiley & Sons. pp: 93-130.
- Hadfield MG, Unabia CRC, Smith CM, Michael TM (1994) Settlement preferences of the ubiquitous fouler *Hydroides elegans*. In: Thompson MF, Nagabhushanam R, Sarojini R, Fingerman M (eds). *Recent developments in biofouling control*. Oxford and IBH, New Delhi, India. pp: 65-74.
- Osman RW, Whitlatch RB (1995) The Influence of Resident Adults on Recruitment - a Comparison to Settlement. *Journal of Experimental Marine Biology and Ecology* 190: 169-198.
- Keough MJ, Raimondi PT (1995) Responses of settling invertebrate larvae to bioorganic films: effects of different types of films. *J Exp Mar Biol Ecol* 185: 235-253.
- Slattery M, McClintock JB, Heine JN (1995) Chemical defenses in Antarctic soft corals: evidence for antifouling compounds. *J Exp Mar Biol Ecol* 190: 61-77.
- Steinert M, Hentschel U, Hacker J (2000) Symbiosis and pathogenesis: evolution of the microbe-host interaction. *Naturwissenschaften* 87: 1-11.
- Hildebrand M, Waggoner LE, Lim GE, Sharp KH, Ridley CP, et al. (2004) Approaches to identify, clone, and express symbiont bioactive metabolite genes. *Nat Prod Rep* 21: 122-142.
- Schmidt EW, Obratsova AY, Davidson SK, Faulkner DJ, Haygood MG (2000) Identification of the antifungal peptide-containing symbiont of the marine sponge *Theonella swinhoei* as a novel delta-Proteobacterium, "*Candidatus Enttheonella palauensis*". *Marine Biology* 136: 969-977.
- Davidson SK, Allen SW, Lim GE, Anderson CM, Haygood MG (2001) Evidence for the biosynthesis of bryostatins by the bacterial symbiont "*Candidatus Endobugula sertula*" of the bryozoan *Bugula neritina*. *Appl Environ Microbiol* 67: 4531-4537.
- Hentschel U, Schmid M, Wagner M, Fieseler L, Gernert C, et al. (2001) Isolation and phylogenetic analysis of bacteria with antimicrobial activities from the Mediterranean sponges *Aplysina aerophoba* and *Aplysina cavernicola*. *FEMS Microbiol Ecol* 35: 305-312.
- Laudien J, Wahl M (1999) Indirect effects of epibiosis on host mortality: seastar predation on differently fouled mussels. *Mar Ecol* 20: 35-47.
- Stachowicz JJ, Hay ME (1999) Reducing predation through chemically mediated camouflage: indirect effects of plant defenses on herbivores. *Ecology* 80: 495-509.
- Paul VJ, Puglisi MP (2004) Chemical mediation of interactions among marine organisms. *Nat Prod Rep* 21: 189-209.
- Dobretsov S, Dahms HU, Tsoi MY, Qian PY (2005) Chemical control of epibiosis by Hong Kong sponges: The effect of sponge extracts on micro- and macrofouling communities. *Marine Ecology Progress Series* 297: 119-129.
- Kelly SR, Garo E, Jensen PR, Fenical W, Pawlik JR (2005) Effects of Caribbean sponge secondary metabolites on bacterial surface colonization. *Aquatic Microbial Ecology* 40: 191-203.
- Krug PJ (2006) Defense of benthic invertebrates against surface colonization by larvae: a chemical arms race. In Müller WEG, Fusetani N, Clare AS (eds). *Antifouling Compounds*, Heidelberg: Springer, pp: 1-53.
- Hadfield MG (1986) Settlement and recruitment of marine invertebrates - a perspective and some proposals. *Bulletin of Marine Science* 39: 418-425.
- Konya K, Shimidzu N, Adachi K, Miki W (1994) 2,5,6-tribromo-1-methylgramine, an antifouling substance from the marine bryozoan *Zoobrottrion pellucidum*. *Fisheries Science* 60: 773-775.
- Sears MA, Gerhart DJ, Rittschof D (1990) Antifouling agents from marine sponge *Lissodendoryx isodictyalis carter*. *J Chem Ecol* 16: 791-799.
- Bobzin SC, Faulkner DJ (1992) Chemistry and chemical ecology of the Bahamian sponge *Aplysilla glacialis*. *J Chem Ecol* 18: 309-332.
- Becerro M, Uriz M, Turon X (1997) Chemically mediated interactions in benthic organisms: the chemical ecology of *Crambe crambe* (Porifera, Poecilosclerida). *Hydrobiologia* 356: 77-89.
- Armstrong E, McKenzie JD, Goldsworthy GT (1999) Aquaculture of sponges on scallops for natural products research and antifouling. *Journal of Biotechnology* 70: 163-174.
- Pawlik JR, McFall G, Zea S (2002) Does the odor from sponges of the genus *Ircinia* protect them from fish predators? *J Chem Ecol* 28: 1103-1115.
- Tsoukatou M, Hellio C, Vagias C, Harvala C, Roussis V (2002) Chemical defense and antifouling activity of three Mediterranean sponges of the genus *Ircinia*. *Z Naturforsch C* 57: 161-171.
- Omae I (2003) Organotin antifouling paints and their alternatives. *Applied Organometallic Chemistry*, 17, 81-105.
- Davis AR (1991) Alkaloids and ascidian chemical defense: evidence for the ecological role of natural products from *Eudistoma olivaceum*. *Mar Biol* 111: 375-379.
- Wahl M, Jensen PR, Fenical W (1994) Chemical control of bacterial epibiosis on ascidians. *Mar Ecol Prog Ser* 110: 45-57.
- Targett NM, Bishop SS, McConnell OJ, Yoder JA (1983) Antifouling agents against the benthic marine diatom, *Navicula salinicola* - homarine from the gorgonians *Leptogorgia virgulata* and setacea and analogs. *Journal of Chemical Ecology* 9: 817-829.
- Standing JD, Hooper IR, Costlow JD (1984) Inhibition and induction of barnacle settlement by natural products present in octocorals. *J Chem Ecol* 10: 823-834.
- Slattery M, Hamann MT, McClintock JB, Perry TL, Puglisi MP, et al. (1997) Ecological roles for water-borne metabolites from Antarctic soft corals. *Mar Ecol* 161: 133-144.
- Tomono Y, Hirota H, Fusetani N (1999) Isogosterones A-D, antifouling 13,17 secosteroids from an octocoral *Dendronephthya* sp. *J Org Chem* 64: 2272-2275.
- Sato A, Fenical W (1983) Gramine-derived bromo-alkaloids from the marine bryozoan *Zoobotryon verticillatum*. *Tetrahedron Lett* 24: 481-484.
- Temraz TA, Houssen WE, Jaspars M, Woolley DR, Wease KN, et al. (2006) A pyridinium derivative from Red Sea soft corals inhibited voltage-activated

- potassium conductances and increased excitability of rat cultured sensory neurons. *BMC Pharmacol* 6: 1-19.
39. Abarzua S, Jakubowsky S (1995) Biotechnological investigation for the prevention of biofouling. I. Biological and biochemical principles for the prevention of biofouling. *Marine Ecology Prog Ser* 123: 301- 312.
40. Steinberg PD, De Nys R, Kjelleberg S (1998) A new method for determining surface concentrations of marine natural products on seaweeds. *Mar Ecol Prog Ser* 162: 79-87.
41. Rittschof D (2000) Natural product antifoulants: One perspective on the challenges related to coatings development. *Biofouling* 15: 119-127.
42. Hirono M, Ojika M, Mimura H, Nakanishi Y, Maeshima M (2003) Acylspermidine derivatives isolated from a soft coral, *Sinularia* sp, inhibit plant vacuolar H(+)-pyrophosphatase. *J Biochem* 133: 811-816.
43. Sheu JH, Ahmed AF, Shiue RT, Dai CF, Kuo YH (2002) Scabrolides A-D, four new norditerpenoids isolated from the soft coral *Sinularia scabra*. *J Nat Prod* 65: 1904-1908.
44. Ojika M, Islam MK, Shintani T, Zhang Y, Okamoto T, et al. (2003) Three new cytotoxic acylspermidines from the soft coral, *Sinularia* sp. *Biosci Biotechnol Biochem* 67: 1410-1412.
45. Kelman D, Kashman Y, Rosenberg E, Kushmaro A, Loya Y (2006) Antimicrobial activity of Red Sea corals. *Mar Biol* 149: 357-363.
46. Kamel HN, Fronczek FR, Khalifa SI, Slattery M (2007) Microbial transformation of 5-episinuleptolide. *Chem Pharm Bull (Tokyo)* 55: 537-540.
47. Kubanek J, Whalen KE, Engel S, Kelly SR, Henkel TP, et al. (2002) Multiple defensive roles for triterpene glycosides from two Caribbean sponges. *Oecologia* 131: 125-136.
48. Maida M, Sammarco PW, Coll JC (1995) Effects of soft corals on scleractinian coral recruitment. I. Directional allelopathy and inhibition of settlement. *Mar Ecol Prog Ser* 121: 191-202.
49. Aceret TL, Sammarco PW, Coll JC (1995) Effects of diterpenes derived from the soft coral *Sinularia flexibilis* on the eggs, sperm and embryos of the scleractinian corals *Montipora digitata* and *Acropora tenuis*. *Mar Biol* 122: 317-323.
50. Rinehart KL, Kobayashi J, Harbour GC, Gilmore J, Mascall M, et al. (1987) Eudistomins A-Q, beta carbolines from the antiviral Caribbean tunicate *Eudistoma olivaceum*. *J Am Chem Soc* 109: 3378-3387.
51. Davis AR, Wright AE (1990) Inhibition of larval settlement by natural products from the ascidian, *Eudistoma olivaceum* (Van Name). *J Chem Ecol* 16: 1349-1357.
52. Walker RP, Thompson JE, Faulkner DJ (1985) Exudation of biologically active metabolites in the sponge *Aplysina fistularis*. II. Chemical evidence. *Mar Biol* 88: 27-32.
53. Hellio C, Tsoukatou M, Maréchal JP, Aldred N, Beaupoil C, et al. (2005) Inhibitory effects of mediterranean sponge extracts and metabolites on larval settlement of the barnacle *Balanus amphitrite*. *Mar Biotechnol (NY)* 7: 297-305.
54. Limnamol VP, Raveendran TV, Parameswaran PS, Kunnath RJ, Sathyan N (2010) Antifouling sesquiterpene from the Indian soft coral *Sinularia kavartiensis* alderslade and Prita. *Indian Journal of Marine Sciences* 9: 270-273.
55. Yang LH, Lee OO, Jin T, Li XC, Qian PY (2006) Antifouling properties of 10 beta-formamidokalihinol-A and kalihinol A isolated from the marine sponge *Acanthella cavernosa*. *Biofouling* 22: 23-32.
56. Blihoghe D, Manzo E, Villela A, Cutignano A, Picariello G, et al. (2011) Evaluation of the antifouling properties of 3-alkylpyridine compounds. *Biofouling* 27: 99-109.
57. Maida M, Sammarco PW, Coll JC (2006) A diffusion chamber for assessing efficacy of natural anti-fouling defenses in marine organisms. *J Exp Mar Biol Ecol* 337: 59-64.
58. Chambers LD, Stokes KR, Walsh FC, Wood RJK (2006) Modern approaches to marine antifouling coatings. *Surf Coat Technol* 201: 3642-3652.
59. Lai D, Li Y, Xu M, Deng Z, Ofwegen L, et al. (2011) Sinulariols A-S, 19-oxygenated cembranoids from the Chinese soft coral *Sinularia rigida*. *Tetrahedron*, pp: 1-12.
60. Pereira RC, Carvalho AG, Gama BA, Coutinho R (2002) Field experimental evaluation of secondary metabolites from marine invertebrates as antifoulants. *Braz J Biol* 62: 311-320.
61. Epifanio RA, da Gama BAP, Pereira RC (2006) 11?,12?epoxyypukalide as the antifouling agent from the Brazilian endemic sea fan *Phyllogorgia dilatata* Esper. *Biochem Syst Ecol* 34: 446-448.
62. Roper KE, Beamish H, Garson MJ, Skilleter GA, Degnan BM (2009) Convergent antifouling activities of structurally distinct bioactive compounds synthesized within two sympatric *Haliclona* demosponges. *Mar Biotechnol* 11: 188-198.
63. Qi SH, Zhang S, Yang LH, Qian PY (2008) Antifouling and antibacterial compounds from the gorgonians *Subergorgia suberosa* and *Scripearia gracillis*. *Nat Prod Res* 22: 154-166.
64. Peters L, König GM, Wright AD, Pukall R, Stackebrandt E, et al. (2003) Secondary metabolites of *Flustra foliacea* and their influence on bacteria. *Appl Environ Microbiol* 69: 3469-3475.
65. Harvell CD, Fenical W, Roussi V, Ruesink JL, Griggs CC, et al. (1993) Local and geographic variation in the defensive chemistry of a West Indian gorgonian coral (*Briareum asbestinum*). *Mar Ecol Prog Ser* 93: 165-173.
66. Puglisi MP, Paul VJ, Slattery M (2000) Biogeographic comparisons of chemical and structural defenses of the Pacific gorgonians *Annella mollis* and *A. reticulata*. *Mar Ecol Prog Ser* 207: 263-272.
67. Fusetani N (2004) Biofouling and antifouling. *Nat Prod Rep* 21: 94-104.
68. Walls JT, Ritz DA, Blackman AJ (1993) Fouling, surface bacteria and antibacterial agents of four bryozoan species found in Tasmania, Australia. *J Exp Mar Biol Ecol* 169: 1-13.
69. Shellenberger JS, Ross JRP (1998) Antibacterial activity of two species of bryozoans from northern Puget Sound. *Northwest Sci* 72: 23-33.
70. Kubanek J, Pawlik JR, Eve TM, Fenical W (2000) Triterpene glycosides defend the Caribbean reef sponge *Erylus formosus* from predatory fishes. *Marine Ecology Progress Series* 207: 69-77.
71. Rubio C (2002) Thèse de l'Université de Paris VI.
72. Sathesh S, Ba-akdah MA, Al-Sofyani AA (2015) Natural antifouling compound production by microbes associated with marine macroorganisms - A review *Electronic J of Biotechnology*.