



Reef Focus: Silent Assassins Part IV

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Last time we explored the toxicants that lurk in even the most productive of recirculating life support systems, which was so thought-provoking, it prompted extensive re-evaluation of husbandry and system design. See: Part I, Appendix II. Herein we investigate three significantly injurious substances that have caused confounding mortalities in recirculating systems.

Marine Safe Stainless Steel

Non-marine safe stainless steel (SS) is made from toxic metals like zinc. Food grade SS316 or SS316L are formulated to resist the corrosive properties of seawater that comprise chromium, nickel, and molybdenum at ratios approaching 16:10:2 (Sandmeyer Steel Company 2014), whereas food grade SS304 lacks molybdenum and is therefore unsuitable. The frames of sump cabinets, impeller shafts, and wire used to mount corals must be SS316 or SS316L, nevertheless, these grades are vulnerable to chloride stress which instigates fractures in warmer seas (Riggs Larsen 2016). Nut and bolt suppliers carry jubilee clips and fixings, while metal supermarkets cut box section to size, and stock frame-assembling plastic inserts (Fig 1.).

Neodymium Magnets: Toxicity and Use

Rare earth metals like neodymium (Nd) are injurious to the juveniles of freshwater rainbow trout (*Oncorhynchus mykiss*) at concentrations two orders of magnitude less than their LC_{50} . Nd^{3+} interfere with indispensable intracellular processes such as DNA repair, anabolism (growth), the metabolism of ammonia (NH_3), and the posttranslational movement of proteins (Dube et al. 2019). Concentrations on wild reefs are inordinately low insofar as they barely exceed 30 picomole (pmol) kg^{-1} ($\sim 3.0 \times 10^{-11}$ mol kg^{-1}) or approximately 4.3 ng l^{-1} (4.3×10^{-9} g l^{-1} ; Chen et al. 2013).

Manufacturers of aquatic equipment have begun to use neodymium magnets for numerous applications including impellers and algae magnets, whereas inert coatings such as polypropylene render neodymium inaccessible and thus harmless. However, ions of Nd will leach when exposed to water. Despite the benefit of replacing non-316 and -316L stainless steel impeller shafts with ceramic, its rigidity has motivated some manufacturers to support each end in relatively soft silicone. Such mounts readily degrade thanks to the vibrational forces common to the impeller chambers of pumps used for calcium reactors and protein skimmers, which continually smashes the impeller into the surrounding walls. Inert coatings are thus abraded. Experienced "reefers" scratch their head as unexplained mortalities coincide with nothing but a noisy pump. Numerous postings on web forums describe anecdotal analogies. Nd LC_{50} analyses have not been carried out on corals, so immediately strip and repair noisy pumps and do not store algae magnets in aquaria.

Every aquarist uses epoxy glues and the following methodology at their own risk, because uncured epoxies are harmful, where severe skin reactions are not uncommon. Gloves, a face mask and visor, and safety glasses are advised. Use in a well-ventilated area and dispose of the mixing paraphernalia in an outdoor trashcan, then fully harden in a garage devoid of people and pets.

Impellers can be coated in a thick layer of less toxic two-part epoxy glue that soft cures in approximately 20 minutes. Suspend the impeller on a bamboo skewer across a coffee mug and apply a thick coating with a toothpick whilst periodically rotating to preclude

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slumping. Ideally leave overnight to fully harden before reassembly, or apply several thinner, faster-curing veneers.



Fig 1. 100 metres of 316L stainless steel wire purchased for 3GBP.

Avoid pumps with non-magnetite impellers with shafts mounted in silicone. Existing mounts can be replaced with short lengths of appropriately-diametered thick-walled tubing. Rubber is neither reef nor freshwater safe (Hartwell et al. 2004) but is far less hazardous than Nd.

Ozone

The energetic sparks generated within ozonisers cleave some of the covalent bonds of dioxygen (O_2) and thus solitary atoms recombine to form the allotrope trioxxygen (O_3 ; Fig 4.; Holmes-Farley 2006). Some of you may recall the characteristic smell of Scalextric® cars as they sparked their way around the track, whereas stratospheric ozone is synthesised by electric storms close to the tropopause (Davis 1973) and the Sun's ultraviolet (UV) radiation from space (Wallace et al. 1996). The bond attaching oxygen (O) to molecular oxygen (O_2) is highly unstable, reactive, and oxidative, therefore exposing gill epithelium to ozone is detrimental, yet it is beneficial when it reacts with a reductant. Furthermore, its legacy is pure molecular oxygen (O_2 ; dissolved oxygen; $DO\uparrow$).

Air vapour lessens ozoniser efficacy and causes N_2 to form nitric acid (HNO_3), which enriches systemwide nitrate (Holmes-Farley 2006). Beads of silica gel housed in transparent canisters designed for pre-drying the air destined for an ozoniser, change colour when saturated with moisture, which are reactivated by heating in a microwave oven.

Ozone can ostensibly transform ammonium to nitrite and nitrate, thus nullifying a requirement for biofilters, for which its competency proves negligible. It enhances oxygen availability and boosts nitrifying microorganisms at lower concentrations, but it sterilises biofilms in abundance. Anecdotal investigations are thus confounded, whereas an objective study highlighted the usefulness of ozone for oxidising nitrite and phenols, but oxidation of ammonium does not occur until these species have been neutralised and at rates that generate secondary oxidants (Schroeder et al. 2011).

Discharging skimmer effluent through granular activated carbon (GAC) sequesters secondary oxidants and provides a substrate upon which surplus ozone can react, yet it rapidly inactivates due to surface oxygen complexes (SOCs; Álvarez et al. 2008), whilst its long-term use, is as ever, moot.

ORP

Oxidation reduction potential (ORP) is defined as the ratio of oxidised to reduced species expressed in millivolt (mV; ASTM D1498-14 2014). ORPs on pristine wild reefs naturally range from 370 to 390 mV, while hobby-grade ORP probes, instruments, and their controllers are notoriously imprecise and *must not* be used to control ozone, denitrifiers, or anything else. They are however, useful

barometers of system health, which are standard field instruments used for measuring ORP in heavily-reduced environments. In the manufacturers' defence, ORP is challenging to determine, whereas commercial sales of accurate monitoring equipment are in the region of 2,500GBP which are analytical grade pH metres fitted with equally precise ORP probes. Potentially hazardous solutions are required to calibrate these apparatuses; hence continuous monitoring is prone to inaccuracy (ASTM D1498-14 2014). ~200GBP ORP apparatuses are not analytical grade. The tip of a probe must be exposed to system water for ~10 days after which they measure more precisely (Wilson, personal communication), because biofilms likely raise performance.



Fig 2. A Weipro 25 mg h⁻¹ ozone generator (ozoniser).

Atomic Number → 1
Symbol ← H
Name → Hydrogen
Atomic Weight ← 1.008

1 H Hydrogen 1.008	2 He Helium 4.002602																
3 Li Lithium 6.94	4 Be Beryllium 9.0121831																
11 Na Sodium 22.98976928	12 Mg Magnesium 24.305																
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955908	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938044	26 Fe Iron 55.845	27 Co Cobalt 58.933194	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.921595	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90584	40 Zr Zirconium 91.224	41 Nb Niobium 92.90637	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
55 Cs Caesium 132.90545196	56 Ba Barium 137.327	57 - 71 Lanthanoids	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.227	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.592	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89 - 103 Actinoids	104 Rf Rutherfordium (261)	105 Db Dubnium (268)	106 Sg Seaborgium (269)	107 Bh Bohrium (270)	108 Hs Hassium (285)	109 Mt Meitnerium (276)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (282)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (289)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)

57 La Lanthanum 138.90547	58 Ce Cerium 140.12	59 Pr Praseodymium 140.90766	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.502	67 Ho Holmium 164.93033	68 Er Erbium 167.259	69 Tm Thulium 168.93422	70 Yb Ytterbium 173.045	71 Lu Lutetium 174.9668
89 Ac Actinium (227)	90 Th Thorium 232.0377	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)

Fig 3. The periodic table of elements. [-] the halogens of group 17.

Oxidants

Secondary reactive oxygen species (ROS) arising from the misuse of ozone, are *sterilising and destructive to all life*. In the past, ozone was exploited to suppress pathogens, but at injurious concentrations. Ozone may be safely applied to significantly reduced water or in negligible amounts. The former is used in fish-only systems, whereas the latter is applied to reefs.

Numerous successful reef aquarists currently applying ozone to clear, bright water must have significant sources of reductants in their systems or else all the inhabitants would be sterilised, hence suddenly turning ozone off may “crash” life support. The sources of these reductants must therefore be diagnosed and eradicated whilst ozone is simultaneously and gradually withdrawn. Why, because diminished water quality is not caused by a lack of ozone.

Covert harmful reductants manifest in numerous and diverse forms, the diagnosis of which is way beyond the capacity of this series. For further guidance consult: The Complete Reef Aquarist (Aslett 2024).

The **Reductants** of concern in order of potency include dissolved hydrogen sulphide gas (H_2S) that ionises and dissociates into hazardous bisulphide ions (HS^-) that are later detoxified to sulphate (SO_4^{2-}); ammonia and ammonium (NH_3 and NH_4^+); nitrite (NO_2^-) which is the dissociated form of nitrous acid (HNO_2); dissolved carbon dioxide (carbonic acid; H_2CO_3), and organic acids such as phenols ($\text{C}_6\text{H}_4\text{OH}$), whereas the dissociated forms of nitric (HNO_3 ; nitrate) and orthophosphoric (H_3PO_4 ; orthophosphate; $\text{H}_2\text{PO}_4^{3-}$) acids are mildly reductive in seawater. Furthermore, retention of CO_2 and N_2 can saturate water and thus leave no room for other solutes such as oxygen. Do not cover reef aquaria and provide *continual* robust “in-tank” turnover.

The Halogens

An atom's outer electrons are referred to as valent because they confer combining power (valency). The atoms of the non-metallic elements that require only one electron to fill their outer orbital to attain the configuration of an ostensibly inert noble gas are the halogens of group 17 (Fig 3.). They are powerful oxidising agents that include fluorine (F), chlorine (Cl), bromine (Br), and iodine (I). They form ionic compounds with reactive metals like sodium (Na^+Cl^-) or react with surplus ozone to form exceedingly toxic secondary oxidants.

Chlorine, bromine, and iodine are abundant in seawater where the autoionization catalyst water, ensures they manifest as anionic chloride (Cl^-), bromide (Br^-), rarely iodate (IO_3^-), and iodide (I^-) with the latter two readily depleting in recirculating systems. Chloride ions (Cl^-) are exceedingly oxidative which frequently capture electrons from both iodide (I^-) and bromide (Br^-), whereas a metal halide is generated when a metal and halogen react.

If ozone is applied to unreduced seawater, the first to be oxidised are the most unstable and abundant ions: Cl^- and Br^- . The overzealous use of O_3 is therefore perceived by the smell of chlorine. Do not inhale gases expelled from protein skimmers because ozone and secondary oxidants are hazardous, whereas ozone forms such compounds within systems supplemented with iodine or where water was exchanged within the last 36 hours (Wilson, personal communication; Latson et al. 2018).

Total Residual Oxidants (TRO)

Secondary ROS include the hydroxyl radical ($\cdot\text{OH}$), hypobromite (OBr^-), hypobromous acid (HOBr), bromite (BrO), and bromate

(BrO_3^-), which are evaluated and expressed as total residual oxidants (TROs) and mg l^{-1} of Br_2 or Cl_2 (Westerhoff et al. 1998; Perrins et al. 2006). Salifert® produce a TRO assay, albeit beneficial as an approximate guide, secondary ROS are exceedingly hazardous and diverse.

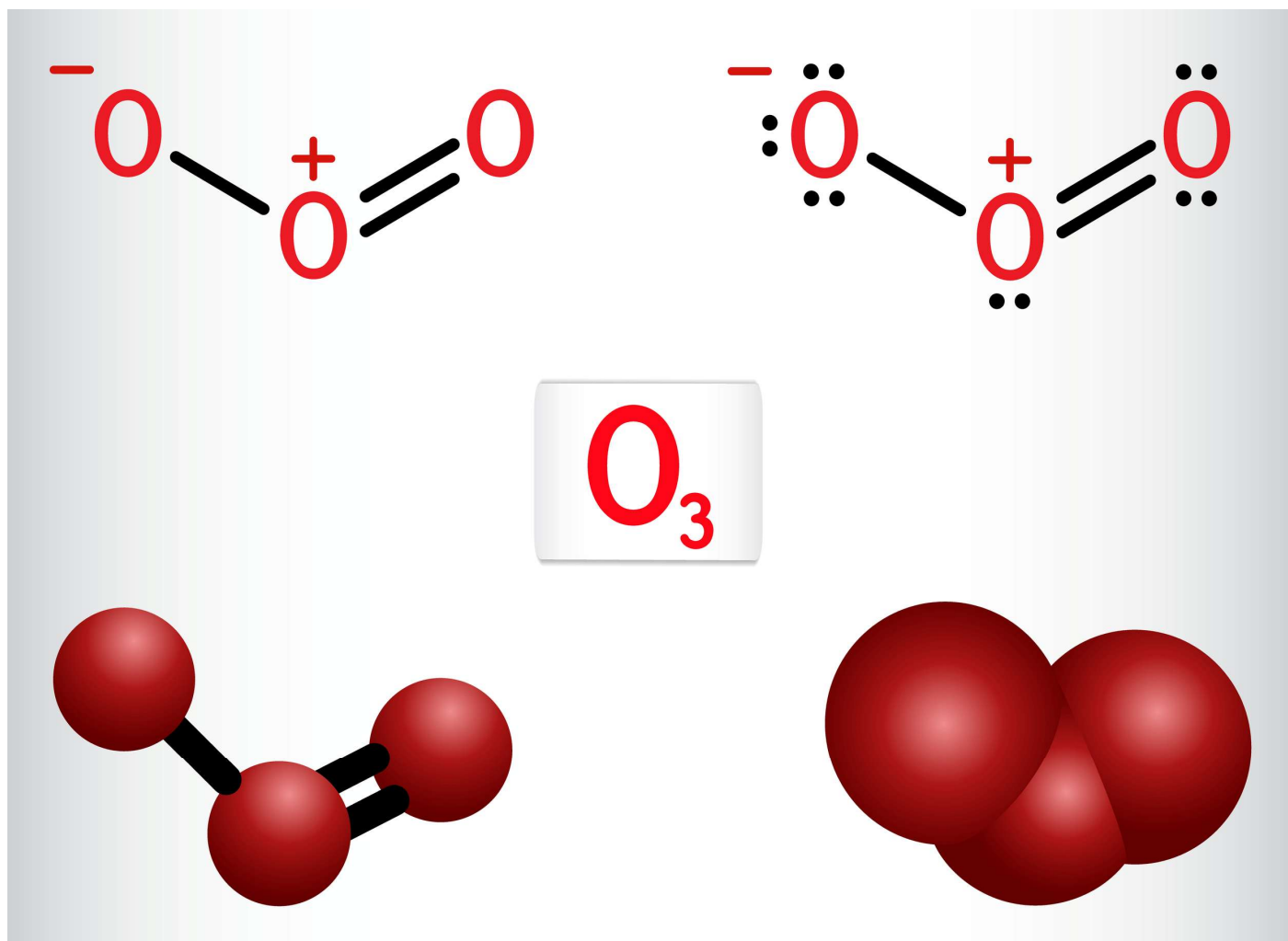


Fig 4. Various ways of representing oxygen's profoundly oxidative allotrope, ozone (O_3 ; trioxygen).

Ozone Administration: Commercial Fish-Only Systems

Ozone is only applied in commercial fish-only systems when the water suddenly becomes dull and grey, which is a remarkable and conspicuous occurrence at "true" ORPs between 260 to 240 mV. Such transformations ordinarily occur after many weeks of heavy feeds, and only then may 50 mg of ozone be applied for every 500 UK gallons (600.5 US gallons) of system volume for merely an hour, after which the ORP will be approximately 320 mV.

Banggai cardinals (*Pterapogon kauderni*) are hypersensitive to secondary oxidants and their juveniles are more so (Fig 5.). Like canaries in coalmines, their sudden death alerts aquarists to secondary oxidants. It is suggested a small shoal of this species are kept as permanent residents in commercial fish-only systems.

The ROS generated by ozone are the same as those produced by the chlorination of seawater, where livestock are protected by surplus sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3$; tap safe; Jones et al. 2006). Oxidation of HS^- yields sulphite (SO_3^{2-}), sulphate (SO_4^{2-}), and thiosulphate ($\text{S}_2\text{O}_3^{2-}$; Cline & Richards 1969) which facilitates a form of precarious equilibrium in reefs with sources of H_2S where a "band aid" of O_3 is applied.

"Burnt" water is sparkly, bright, and very clear. It is more noticeable than its inhabitants. Owing to oxidising and sanitising chloramines, the ORP of UK mains "tap" water ranges from 370 to 380 mV.

Ozone in Reefs

We use far less ozone in a reef than is present in nature because applying ozone to clear, bright reef water creates harmful secondary oxidants, which jeopardises all the inhabitants including corals and thus proceed with extreme caution.

Ozone concentrations in natural seawater range from 0 to 0.1 mg l^{-1} (ppm; Garland & Curtis 1981), and the smallest available ozonisers are typically 25 mg h^{-1} which equates to $\sim 0.01 \text{ mg l}^{-1} \text{ h}^{-1}$ in a 500 UK gallon (600.5 US gallon; 2,273-litre) reef, nevertheless, simply applying such quantities to unreduced water will decimate livestock in an **optimised** system.

A 25 mg h^{-1} ozoniser was energised for 5 seconds every two hours for years in a Reef Ranch™ 500 UK gallon reef, which demanded the purchase of a digital timer capable of measuring and activating at 1-second intervals. Water lost through sales was replaced and a 5 percent water change was performed weekly, after which ozone was not applied for two days. All genera, were at one time or another, represented, and all thrived. The author is not suggesting, albeit the point, such negligible quantities have significant impacts; however, it is noteworthy that traces of ozone are present in the wild yet are essentially absent in aquaria.



Fig 5. Banggai cardinalfish, *Pterapogon kauderni*, suddenly die when exposed to harmful secondary oxidants generated by the misuse of ozone.



Fig 6. A colony of *Acropora* with rapid tissue necrosis (RTN).

Rapid Tissue Necrosis (RTN) or shutdown reaction was first reported in the late 1970s (Antonius 1977) which mostly impacts SPS colonies where it denudes the skeleton from 1 to 3.9" (2.5 to 10 cm) per hour (Borneman 2002). Both wild and captive studies concluded that *Acropora* and *Pocillopora* were most susceptible (Luna et al. 2007). The loss of tissue is so immediate the observer can see the flesh peel from the skeleton (Fig 6.). Associated with housing corals in poor conditions like those of immature systems with negligible ammonia-oxidising communities, healthy tissue and bare skeleton typically share a discrete boundary, which may be indicative of the bacterial metallo- and serine-proteases of *Vibrio vulnificus* (Wang et al. 2008). Contrasting findings suggested RTN may be caused by the coral bleaching and prawn pathogen, *Vibrio harveyi* or inorganic toxins (Borneman 2001; Borneman & Lowrie 2001; Luna et al. 2007; Calfo 2009; Osinga et al. 2012), whilst the author has observed RTN in systems contaminated with hydrogen sulphide. Other studies have associated RTN with diminished DO (Haas et al. 2014), and like HS⁻, secondary oxidants trigger cellular necrosis (Aslett 2024) while a form of pre-programmed cell death called apoptosis, is typically, but not always, prompted by telomeric shortening and an inability to divide (Zhang et al. 1999).

The author hopes this short series has empowered reef aquarists with the necessary to design and operate authentic natural systems that free up living resources hitherto monopolised by detoxification, whose beneficial repercussions have yet to be revealed.

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