FISHING WITH DRONES

A PERSPECTIVE ON REGULATIONS, IMPLICATIONS, ECOTOURISM AND ENVIRONMENTAL RISKS FOR SOUTH AFRICA.

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Executive Summary

In 2015, regulations were promulgated regarding the use of remotely-piloted aircraft (RPAs) or drones in South Africa by the South African Civil Aviation Authority (SACAA). The Regulations detail what type of use and when the use of an RPA is classified as private or commercial use. In the case of recreational fishing, provided the operator is not leading a guided trip, drone fishing would be regarded as ‘private use’, and theoretically would not be necessary for an operator to obtain a licence from the SACAA. However, some may argue that their drones fall under the definition of toy aircraft and thus fall out of the scope of these SACAA regulations. The South African Model Aircraft Association (SAMAA) regulates the use of toy aircraft (or model aircraft) and prohibits the “dropping or discharging of things” by all model aircraft, thus creating a prohibition on the use of dropping items such as bait during drone fishing.

Although there are no specific drone fishing regulations in South Africa, the Regulations within the Marine Living Resources Act defines angling as "recreational fishing by manually operating a rod, reel and line or one or more separate lines to which no more than ten hooks are attached per line”. Therefore, angling is limited to fishing by manually operating a rod, reel and line, and excludes the use of electronic devices, including RPA’s.

In South Africa, drone fishing typically use RPA’s to transport and drop lures or bait offshore while still attached to a rod and line for the purposes of catching fish, including sharks. The advantage of using an RPA include giving an extended reach offshore, the ability to target specific individuals and reconnaissance.

The ethics of fishing with an RPA is debated extensively, but advances in technology give a fisherman an advantage to target individuals which may have been previously hard to target and catch. Many drone fishermen argue that RPAs are used for catch-and-release and have little impact on the marine environment. However, post-release mortality remains a concern because of stress, injuries, and increased susceptibility to depredation.

RPAs are also indirectly and loosely regulated for other purposes in the Marine Living Resources Act: Management of Boat Based Whale Watching and Protection of Turtles Regulations, and in the definition of ‘gear’ for purposes of fishing, the National Environmental Management: Biodiversity Act, 2004: Threatened or Protected Marine Species Regulations, the National Environmental Management: Protected Areas Act 2004.

Despite the ethical and conservation arguments around the use of RPAs for fishing, they do provide an alternative fishing method to people with disabilities as well as generating footage that can be used in creating awareness about the marine environment. Furthermore, RPA gear sales can benefit a niche market and are being produced in South Africa and traded via e-commerce.

Over 20% of South Africa’s line fish stocks are over-exploited or collapsed. Globally the recreational linefish sector is being recognised for its impacts on fish stocks, environmental degradation through fishing tackle adding to marine debris, the increased susceptibility to barotrauma, physiological stress, injury and post-capture mortality to species while potentially making catches highly efficient, and creating access to areas previously unexploited.

The SACAA has undertaken their mandate to regulate the use of RPAs, although evidence suggests that the law enforcement entities and officers severely lack training, knowledge and understanding of RPA regulations in South Africa, including in the jurisdiction of environmental law.

Without rapid and proactive enforcement by DFFE, the use of RPA’s in the coastal zone and marine environment will continue to be in conflict with other users of the airspace and public beaches.

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1. Introduction

The first known concept of a 'drone' dates back to 1849 when Austria attacked Venice using 200 unmanned balloons filled with explosives[1]. In the 1930s, the U.S. and British militaries began to experiment and develop unmanned aircraft for insurgencies in the first World War[2]. Later during the Vietnam War, drones were used for purposes such as "acting as decoys in combat, launching missiles against fixed targets, and dropping leaflets for psychological operations," according to the Imperial War Museum, London[2].

These robotic or Unmanned Aerial Vehicles (UAVs) operate without a pilot on board and with different levels of autonomy. A drone's autonomy level can range from remotely piloted, where a person controls its movements, to extremely advanced autonomy, where it relies on a system of sensors and LIDAR (Light Detection and Ranging), which is a remote sensing method used to examine the surface of the Earth, to calculate its movements and flight.

Although drones or Unmanned Aerial Vehicles (UAV) were originally developed for the military and aerospace industries, they soon became mainstream and were used in emergency rescue, medical supply delivery to remote areas, filming and conservation and monitoring. As technology became more readily available and cost-effective, they have become popular for recreational purposes, including photography and fishing.

There are generally three types of drones: Single rotor helicopters, which look like small helicopters, powered by gas or batteries, have long flight times, usually incorporated with advanced sensors and LIDAR systems and are used to survey land, research storms and map erosion caused by global warming. Multi-rotor drones are generally the smallest and lightest, powered by batteries and also the most popular with aerial vehicle hobbyists, photographers and fishermen. They have shorter flight times of 20-30 minutes with light payload capabilities, such as cameras. Fixed-wing drones are generally larger and exceptionally fuel efficient because of their design and require runways for take-off and landing. They are used by the military and in rescue operations when delivery of gear or equipment is needed.

In this document, the use of drones, UAV's and Remotely Piloted Aircraft (RPA) in the coastal zone and marine environment are investigated in relation to other users, legislation and environmental risks.

Drone fishing[3], herein referred to as Remotely Piloted Aircraft (RPA) angling, is, simply put, where one uses a fishing line from a rod and reel attached to the RPA. The line is free-spooled, and the RPA is used to place the terminal tackle near the fish or fishing area, which may or may not be seen in real-time on a screen associated with the remote control. For the purposes of this report, drones are referred to as RPAs, as per the definition within the South African Civil Aviation Act.

Strictly speaking, angling and fishing are different by definition: fishing being the act of catching fish, while angling is a form of fishing with a rod, line and an angle (hook). Angling is the art or sport of fishing with a rod and line, where the objective is to catch fish, not necessarily for harvest or consumption. For the purposes of this document, 'fishing' is used as an all-inclusive term that includes angling and may or may not imply that the objective is to catch fish for food.

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[1] https://www.historytoday.com/archive/bombs-over-venice
[2] https://interestingengineering.com/a-brief-history-of-drones-the-remote-controlled-unmanned-aerial-vehicles-uavs
[3] https://southernboating.com/life/fishing/drone-fishing/

2. South African legislation pertaining to Remotely Piloted Aircraft (including drones)

Several pieces of legislation deal with the use of RPA's, although for this report, only aviation and environmental law are briefly discussed. Interestingly, although environmental regulations were probably not drafted with RPA's in mind, they have effectively controlled their use in the vicinity of various species and natural spaces.

2.1. Aviation Law

According to the Civil Aviation Act 2009, an RPA is defined as 'an unmanned aircraft which is piloted from a remote pilot station, excluding model aircraft and toy aircraft', thus including the RPA commonly referred to as a drone. The Civil Aviation Act forms the basis for regulating RPAs in South Africa, while the South African Civil Aviation Authority (SACAA) has a mandate to regulate civil aviation activities to ensure acceptable levels of aviation safety and security within South Africa and among operators. Their mandate and associated legislation focus on four key areas:

1) Public safety, the physical safety of individuals and groups of people.
2) Property safety, the safety and liability of property being damaged.
3) Rights, the protection of human, constitutional, and legal rights as an individual or organisation; and
4) Aviation safety, where the safety of other users of the airspace is protected.

The South African Department of Transport and the SACAA have developed regulations, technical standards, technical guidance material, and various circulars to govern RPAs. Regulations governing RPAs were issued by the Minister of Transport on May 27, 2015. These regulations, issued as an amendment to the 2011 Civil Aviation Regulations,https://www.loc.gov/law/help/regulation-of-drones/south-africa.php - _ftn5 now constitute Part 101 of these Regulations, and are known as the Eighth Amendment of the Civil Aviation Regulations (2015) when referenced separately. Under section 163 of the Act and part 11 of the 2011 Regulations, the Director of Civil Aviation also issued technical standards on RPAs known as the South African Civil Aviation Technical Standards (SA-CATS). Both of these took effect on 1 July 2015. In addition, the Director has issued several aeronautical information circulars (AICs) applicable to RPAs. Further to this, the SACAA issued the Technical Guidance Material for RPAS, Part 101 in September 2015.

The application of this legislation applies to what are known as Class-1 and Class-2 RPA and to owners, operators, pilots and those who maintain such RPA. These classes are defined in the SA-CATS as Class-1 and Class-2 RPAs, and are further divided into subclasses: Class-1A (less than 1.5 kg / 3.3 pounds), Class-1B (less than 7 kg / 15.4 pounds), and Class-1C and Class 2A (less than 20 kg / 44 pounds). The application of the Regulations does not extend to:

- autonomous unmanned aircraft, unmanned free balloons and their operations, or other types of aircraft that cannot be managed on a real-time basis during flight; and
- aircraft operated in terms of Part 94 (i.e. non-type Certificated Aircraft) of the Civil Aviation Regulations
- model aircraft, defined as 'heavier-than-air' aircraft of limited dimensions, with or without a propulsion device, unable to carry a human being and to be used for competition, sport or recreational purposes rather than unmanned aeronautical vehicles (UAV) developed for commercial or governmental, scientific, research or military purposes, and not exceeding the specifications as set by the Federation Aeronautique Internationale as listed in the SA-CATS; and

- toy aircraft defined as ‘a product falling under the definition of aircraft which is designed or intended for use in play by children’.

According to the South African Model Aircraft Association (SAMAA), in the *Definition and Specification of model aircraft Operations Manual* (Issue 3, PO18, 2012), section 2.7, the following are prohibited for all model aircraft:

f) any ballast or heavy parts subject to jettisoning;
k) any device which allows a model to be flown automatically to a selected location.

Furthermore, section 5.9 of the SAMAA policy on *General Rules & Guidelines for Operation of Model Aircraft* (Issue 2, PR03, 2012) also prohibits “Dropping or discharging of things”, and reads “*It is prohibited to cause any ballast or any other heavy part to be dropped or discharged from an unmanned aircraft (model aircraft) in flight. Any ballast or material discharged may only be water or sand. This clause also prohibits the carrying of, or discharge of, pyrotechnics from a model aircraft in flight*.”

Although operationally, model aircraft and toy aircraft may be excluded from the above Regulations, any sized aircraft, be it a model aircraft or toy aircraft, may not discharge or drop a payload (i.e. bait). Therefore, if an aircraft, regardless of size partakes in dropping a payload, the Regulations are triggered and the pilot is required to be in possession of the appropriate certification.

Under the Regulations, different uses of RPAs are permitted. These are for i) private, ii) commercial, iii) corporate, and iv) non-profit purposes.

For the purposes of this document, drone fishing, or RPA angling by the recreational fishing sector, would be considered as ‘private use’, and is defined in the Regulations as “the use of an RPA for an individual’s personal and private purpose where there is no commercial outcome, interest or gain”.

Private operations are subject to specific restrictions. These include:

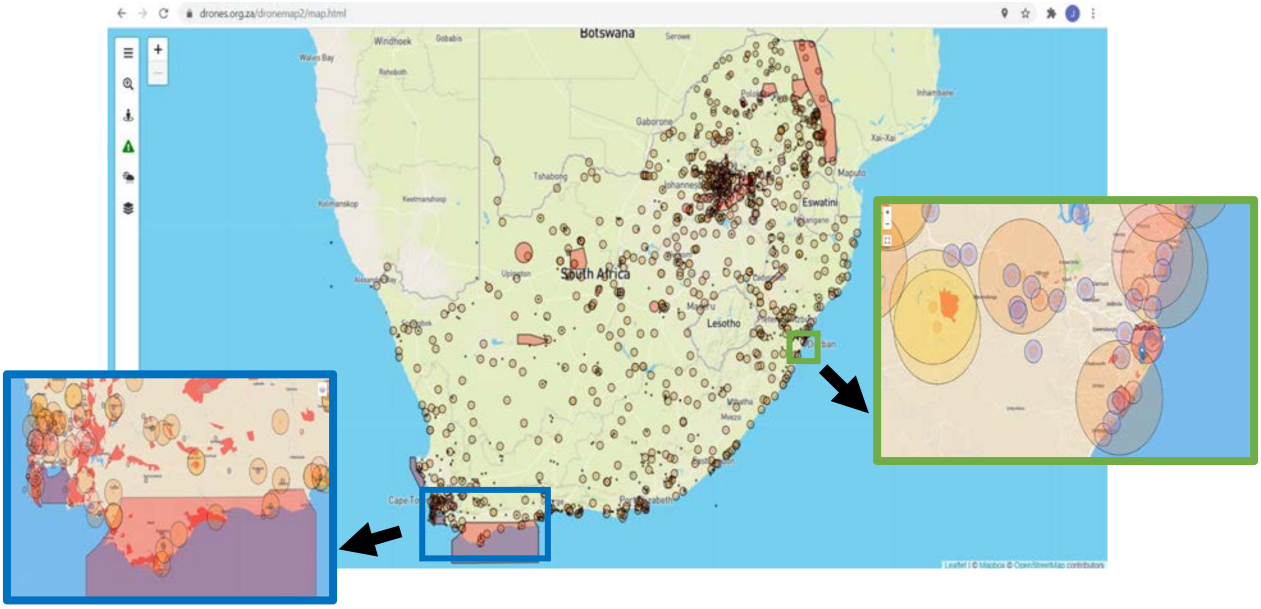
- use may only be conducted with a Class-1A RPA (less than 1.5 kg in weight) or Class-1B RPA (less than 7 kg in weight);
- cannot be flown more than 400 feet (~120 m) above the ground;
- may only be operated in Restricted Visual Line Of Sight (R-VLOS), specifically, “within 500 meters of the remote pilot and below the height of the highest obstacle within 300 meters of the RPA, in which the remote pilot maintains direct unaided visual contact with the RPA to manage its flight and meet separation and collision avoidance responsibilities”;
- may only be operated over property owned by the operator or other property with the permission of the owner.

The Regulations also impose restrictions on certain uses of RPA, including:

- an RPA may not tow another aircraft, perform aerial or aerobatic displays, or be flown in formation or swarm;
- may not be flown within a 10 km radius of an airfield, within restricted or prohibited airspace, or above or near a sensitive area, including a nuclear power plant, correctional institution, police station, crime scene, or court of law;
- may not be operated directly overhead of any person or within a lateral distance of 50 m (164 feet) from any person;
- may not be used for the purpose of releasing, dispensing, dropping, delivering or deploying of an object or substance; and
- may only be used in daylight and in clear weather conditions.

Several online applications[4],[5] have been developed to assist RPA operators to identify the no-fly zones or restricted areas (see map below). These are also available in mobile applications.

Screenshot of Dronemap.org.za where restricted and no fly-zones are indicated



Private RPA operators are exempt from various rules applicable to other forms of RPA use. These include the need for approval and registration of an RPA, personnel licensing requirements, and RPA operator certificate and maintenance requirements. They are also exempt from rules governing the conveyance of dangerous goods, and safety considerations such as ensuring an RPA is in a “fit-to-fly condition”. They are further exempt from regulations on the manner in which flight time is recorded and reported, and from the use of flight logbooks, power reserves, first-aid kits, and hand-held fire extinguishers.

In addition to the above, the pilot must observe all statutory requirements relating to liability, privacy and any other laws enforceable by any other authorities, as well as avoiding negligence such as:

- collision with other aircraft, with possible fatal results,
- injury to the public,
- damage to property; and
- legal liability for breaking laws such as privacy by-laws and other laws enforceable by other authorities.

2.2. Environmental law

In the primary legislation pertaining to marine and coastal environment, there are no specific RPA or drone fishing regulations in South Africa. However, the Regulations within the Marine Living Resources Act, 1998 (Act No. 18 of 1998) defines angling as "recreational fishing by manually operating a rod, reel and line or one or more separate lines to which no more than ten hooks are

[4] https://www.google.com/maps/d/viewer?mid=1dysv62Uj_IMC07jtE99-x8iRVNU&ll=-28.65139668274994%2C24.422016000000006&z=6
[5] https://drones.org.za/drone-map/

attached per line”. Therefore, angling is limited to fishing by manually operating a rod, reel and line, and excludes the use of electronic / motorised devices, such as bait-carrying drones, bait carrying remotely controlled boats, and motorised electric reels.

In South Africa, the use of RPAs in the marine environment was first brought to the fore in the management of humpback and southern right whale migrations, where the behaviour of ‘harassment’ was prohibited in the Marine Living Resources Act (MLRA) Regulations for the Management of Boat Based Whale Watching and Protection of Turtles (2008), where ‘No person shall, except on the authority of a permit (a) kill, or attempt to kill, fish for or harass a whale or a dolphin, in section 3. Furthermore, ‘harassment’ was defined in the National Environmental Management: Biodiversity Act (NEMBA 10/2004): Threatened or Protected Marine Species Regulations (2017) as, “to undertake a behaviour or conduct that threatens, disturbs or torments a live specimen of a listed threatened or protected marine species, and includes (b) approaching a whale with a vessel or aircraft closer than 300 meters”; or (c) approaching a white shark predating on natural prey with a vessel or aircraft closer than 80 meters.

The practice and restriction of any flying aircraft (including RPAs) within South African Protected Areas, Marine Protected Areas (MPAs) and World Heritage Sites was prohibited in terms of the National Environmental Management: Protected Areas Act (NEM:PAA 2004) section 47 which states that it is illegal to fly below 2500 feet above the highest point of any national park, with any aircraft without the express permission of the Management Authority, thereby making protected areas no-fly zones for all unauthorised aircraft systems. A member of the public using a drone, for any purpose, including fishing would be in contravention of Section 47 and therein would be guilty of an offence in terms of Section 89(1)(a) of NEMPAA, unless written permission is granted by the management authority under Section 3A(b)(i) after having paid the prescribed fee should one be set as per Section 3A(b)(ii).

Should a person be caught, charged and found guilty for flying a drone in contravention of Section 47 of NEMPAA, they may be liable, to a fine not exceeding R5 million or imprisonment for a period not exceeding five years for a first offence as per Section 89 (2), while the penalty for a second offence would be double the first order.

Delegated / designated Conservation Management Authorities (iSimangaliso Wetland Park Authority, SANParks, Ezemvelo KZN Wildlife, Cape Nature, Eastern Cape Parks) may grant permission for the use of a drone in a Protected Area, subject to reasonable conditions. Similarly they may also refuse to grant permission, provided a good enough reason is given to the applicant. In addition to this filming and/or photography within Protected Areas may also infringe on policies of a Management Authority.

Most likely, when the initial regulations were drafted, their intended use was not to control the use of drones or RPAs, but these pieces of legislation have effectively prohibited the use of RPAs in the close proximity of whales, dolphins, turtles, seals, nesting birds and some sharks.

3. Use of RPAs in conservation and research

RPAs are becoming effective conservation, research and monitoring tools. Drones give one the ability to obtain accurate data and high-resolution images in a faster, cheaper and safer manner (Koh and Wich 2012; Will et al. 2014). The use of drones in the conservation sector is not limited to monitoring species and their habitats but extends to management purposes, technical services, eco-tourism marketing, law enforcement, anti-poaching and search-and-rescue efforts (Jewitt D. and Wijnberg 2018). Literature on the use of drones in biological sciences is increasing rapidly, as is monitoring of a wide range of species in both the terrestrial (Jones et al.2006; Vermeulen et al. 2013) and the marine environment, including species such as turtles, whales, dolphins and dugongs (Hodgson et al. 2013). In addition, mapping habitats using RPAs allows an assessment of habitat extent and condition (Gonçalves et al. 2016; Habel et al. 2016).

However, the use of drones to monitor animals may create undesirable and unforeseen impacts on wildlife (Hodgson and Koh 2016). Even if there is no visual response from the animals there may still be physiological stress responses such as elevated heart rates (Ditmer et al. 2015). In addition, it needs to be recognised that RPAs are becoming used extensively in biological research, and Nisbet and Paul (2004) argued that field biologists have an obligation to evaluate their impact of RPAs to minimise any adverse effects to their study subjects.

4. *Fishing with RPAs (RPA angling / drone fishing)*

In South Africa, anglers typically use an RPA in two ways. Firstly, lures or bait may be transported offshore while still attached to a rod and positioned in the water. Secondly, RPAs may be used to spot fish from the air and drop a lure or bait. In less common cases, a lure or bait is dropped into the water, a fish is hooked and then hoisted out of the water.

However, the practice of using RPAs in metropolitan areas are written into by-laws which prohibit the use of RPAs in public areas, specifically for fishing/angling. For instance, according to the City of Cape Town, Coastal by-laws (2020), section 6(2) prohibits fishing to take place using equipment in such a manner 'to cause danger to any other person or in such a way as to cause an obstruction to or to interfere with personal privacy of any other person'. The Ethekwini Beach by-laws (2015), section 15(3) says that, 'no person may, while fishing, or while on the beach use or permit the use of fishing equipment...in such manner as to cause danger or annoyance to any other person or in such a way as to cause an obstruction to or to interfere with the comfort or personal privacy of any other person'. Both sets of by-laws speak to the use RPAs in terms of personal privacy and annoyance of other beach users.

On 24 February 2022, the Department of Forestry, Fisheries and the Environment released a notification informing the public that fishing with drones was illegal. This notification and the definition within the MLRA were tested in the High Court in June 2022, with the subsequent Appeal being dismissed later in October 2022.

Currently, there are no specific 'drone fishing regulations, however the MLRA does not allow for drone fishing through the definition of 'gear' which is defined in Section 1 of the MLRA, where in relation to fishing, any equipment, implement or other object that can be used in fishing, including any net, rope, line, float, trap, hook, winch, aircraft, boat or craft carried on board a vessel, aircraft or other craft". It can be argued that RPAs are "gear", but in this case, the RPA still must comply with any standards that may be prescribed by other legislation, such as in Section 45(a) of the MLRA which determines that 'no person shall use, possess or have control of any gear which does not conform to the standards that may be prescribed for that type of gear'. Therefore, RPAs used for fishing or angling must conform with the rules and regulations stipulated in the relevant Civil Aviation Act and Regulations thereof, which are described, in detail above (see section 2). The very nature of 'fishing or angling with drones' does not conform to the SACAA regulations because bait / lures are transported and dropped / deployed by means of an RPA, this includes with the use of model or toy aircraft.

4.1. *What are the benefits and appeal of RPAs in fishing?*

RPA fishing is not supported by all fishermen, including the South African Shore Angling Association (SASAA)[6]. Some argue that: it's a detached way to harvest fish[7], it takes the 'sport' out of sport-fishing[8], it changes the way people are learning to read the environment and it takes away from the challenge and skill of angling and fishing. Arguably, apart from 'for the pot' fishermen, the joy of recreational fishing lies in not knowing what the exact possibility is of catching a fish you are targeting. It has been argued on social media that the very experience of angling and the mystery of not knowing what to expect is the very root of why people keep casting day after day, and it speaks to human satisfaction, pleasure and quality of life.

However, the change and uptake of technological advances and innovation is based on a model developed by Rogers (1962), where he describes that an innovation will initially only reach a small group of like-minded individuals, later being recognized by a larger group of potential users and then only after some tried-and-tested time, will the innovation become fashionable among a majority and reach the mainstream. However, by this time the innovators have most likely already have begun to modify their designs, thus reviving the cycle once more. According to Cooke et al. (2021), although a generalisation, it is safe to say that most innovations within the recreational fishing sector will either make the fishing activity less challenging or they will make fishing more effective in terms of catch per unit effort.

There are various ways in which an RPA can be used in fishing/angling:

- Extended reach, where an RPA makes it possible to bypass obstructions like rocks, reefs and the surf zone waves which usually limit the normal casting range, thus making fishermen independent of casting skill and their strength. This also gives anglers the ability to fish in previously inaccessible areas.
- Reconnaissance[9], where many RPAs are fitted with high-quality cameras to view the area below, giving the advantage of an 'eye in the sky' and the ability to factor in currents, habitats, changes in depth and fish behaviour. Furthermore, fish gather around underwater structures and RPAs provide the ability to search an area for schools, bait balls and aggregations.
- RPA Casting[10], the majority of anglers don't cast more than 50 – 100 m, but with an RPA a cast can be as long as the length of the fishing line, thus extending the reach considerably; and
- RPA Casting and Pulling[11], which is a practice not particularly popular in South Africa but an effective means whereby the RPA will place your hook and bait or lure in the vicinity of the fish, and bring the catch back to the beach or vessel. This practice is limited by the size of the drone.

The ethics of fishing with an RPA is debated online extensively among fishing groups, but it needs to be argued whether an RPA is worse than using a fish finder[12]. Although ski boat anglers have this advantage, the addition of RPAs to an angler's arsenal effectively gives fish even fewer places to hide and an increased chance of being harvested. Ultimately, both these technologies can give a fisherman

[6]https://www.fishingindustrynewssa.com/2021/07/25/update-drone-fishing-conversation-leads-to-call-for-regulation-over-any-kind-of-ban/
[7]Montana (USA) Fish and Wildlife Commission (https://helenair.com/outdoors/montana-to-consider-limits-on-fishing-drones-remote-controlled-boats/article_a1654afc-c37c-5e3a-a67a-cfb03acb5ec4.html)
[8]https://fishingbooker.com/blog/drone-fishing-is-it-really-fishing/
[9]https://fishingbooker.com/blog/drone-fishing-is-it-really-fishing/
[10]https://fishingbooker.com/blog/drone-fishing-is-it-really-fishing/
[11]https://fishingbooker.com/blog/drone-fishing-is-it-really-fishing/
[12]https://yourbassguy.com/drone-fishing/

an advantage to target individuals that may have been previously hard to target and catch, thus placing a disproportionate impact on fish populations.

4.2. Catch-and-release angling

The South African Drone Angling Association has stated on record that many of their members are not fishing for food and that they participate recreationally and operate as a catch-and-release[13] fishery. Globally, catch-and-release is aimed at minimizing the impact on fish stocks, even though post-release mortality is substantial (Muoneke and Childress 1994) and remains a concern due to the risk of stress, injuries, and increased susceptibility to natural predation for fish (Bartholomew and Bohnsack 2005; Cooke and Schramm 2007; Raby et al. 2014, Whitney et al. 2017). According to Alverson et al. (1994), the impact of post-release mortality in the recreational fishery is analogous to that of bycatch discards in commercial fisheries.

Fish captured by hook and line may experience physiological stresses such as increased levels of lactate and cortisol in the blood, and their associated recovery times are species-dependent (Tomasso et al. 1996; Bartholomew and Bohnsack 2005). Furthermore, Cooke et al. (2001) and Arlinghaus et al. (2007) have demonstrated that removing a fish from the water and exposing it to air can lead to severe bradycardia and elevated cardiac output. Sub-lethal effects such as these may result in reduced growth rates and potentially reduced reproductive output (Cooke et al. 2006). While such impacts are difficult to quantify (Pollock and Pine 2007), they do suggest that catch-and-release angling may have subtle long-term effects on fish populations (Mann et al. 2018).

This problem could be exacerbated in areas exposed to intensive catch-and-release where individuals might be captured multiple times, leading to population-level impacts where total effort is high (Coggins et al. 2007 and Johnston et al. 2015). Mann et al. (2016) documented that the growth of speckled snappers (*Lutjanus rivulatus*) recaptured multiple times compared to those that were only recaptured once showed no significant difference but conceded that their finding was likely to be very species-specific. This, however suggests that catch-and-release impacts, even at high-intensity rates, can be mitigated by good fish handling practices (Mann et al. 2018).

Catch-and-release is a supported and promoted activity, as well as a form of management practice, in South Africa. However, evidence suggests that catch-and-release is not a good management strategy for all species in all areas (Mann et al. 2018). Bartholomew and Bohnsack (2005) suggested that although catch-and-release angling is an important activity in an MPA, it does result in some disturbance, injury and mortality, which may conflict with some of the goals of a no-take MPA. Later, Cooke et al. (2006) suggested that catch-and-release is potentially compatible with no-take MPAs under specific conditions together with regulations and awareness. They argued that catch-and-release can enhance the achievement of conservation and management goals associated with MPAs, while maintaining public and tourism support. According to Mann et al. (2018), catch-and-release angling does have a lower negative impact on species in comparison with recreational harvest fisheries. However, with the correct zonation and management of areas, catch-and-release angling could potentially offer buffer areas adjacent to no-take MPAs, or as standalone areas where fish conservation can be improved.

[13] https://www.iol.co.za/sunday-tribune/news/anglers-take-to-the-skies-with-drones-a8733624-1637-435a-acc2-d0e87e9c1106

4.3. Benefits of RPA angling: people with disabilities and eco-tourism

Despite the ethical and conservation arguments around the use of RPAs for fishing, they do provide an alternative fishing method to people with disabilities[14,15,16] as well as generating footage to be used in awareness and education about the marine environment. Furthermore, Ditton et al. (2002) suggests that fishing gear sales online globally contributes substantially to the angling tourism industry. The cost of fishing RPAs range from ~R8,000 upwards. From an economic point of view this is an eco-tourism niche market which is yet to be capitalised upon, with online distributors based in South Africa selling RPAs to over 100 countries[17]. The proportion of sales of these RPAs to local versus international markets is still to be determined, although Cooke et al. (2021) believe that drone fishing is more popular and freely available in developed countries. However, availability to undeveloped countries is increasing as a result of e-commerce.

5. Implications marine biodiversity

Cooke and Cowx (2004) estimated that 11.5% of the global population participates in recreational fishing, which extrapolates to 47.1 billion fish being landed and 17.1 billion fish being harvested, weighing ~10.9 million metric tonnes globally per year. Therefore, the recreational fishery could potentially equate to 14% more than the global combined commercial inland and marine finfish fisheries of 80.5 million metric tonnes per year (FAO 2003; Cooke and Cowx 2004).

Evidence of the South African linefishery having a severe impact on species was documented by van der Elst and de Freitas (1988), who suggested that the species composition of landings such as large, endemic reef fishes indicated overfishing. Various studies, strategies and changes were undertaken in an attempt to regulate the linefishery in South Africa, such as the development of the South African Linefish Management Protocol (Griffiths et al. 1999), national fishing permit system (1998), beach driving ban (2002), recognition of subsistence fishers (2003), implementation of commercial fishing rights (2003-2006), species-specific linefish regulations (2005) and the implementation of fish lists in MPAs (2016 and 2020).

Mann et al. (2013) stated that 11 of 139 linefish species were over-exploited and 19 species had already collapsed, but the stock status of only 56 species were known. This is concerning and highlights the urgent need for stock assessments. Cognizance should also be taken of the need for precautionary actions when regulating current and emerging pressures on the linefish sector in South Africa to prevent further stock collapses, such as RPA / drone fishing. It is becoming more accepted that the failure to recognize the impacts of recreational fishing to fish stocks, environmental degradation, and alterations in ecosystems is placing ecologically and economically important resources at risk (Cooke and Cowx 2004).

As highlighted above, fishing with an RPA provides an advantage to the operator over someone who is simply casting and retrieving with a rod and reel. Froese et al. (2017) argues that most fish populations are usually resilient to modest fishing. However, fishing efficiency can range from

[14] https://www.news24.com/witness/news/lets-keep-with-the-times-angler-defends-drone-fishing-20210305
[15] https://weareexplorers.co/drone-fishing-next-big-thing/
[16] https://fishingbooker.com/blog/drone-fishing-is-it-really-fishing/
[17] https://www.iol.co.za/sunday-tribune/news/anglers-take-to-the-skies-with-drones-a8733624-1637-435a-acc2-d0e87e9c1106

inefficient, where fishers are uninformed and catches are random to highly efficient (Cooke et al. 2021), thus making over-exploitation of marine life is a real possibility.

6.1. Safe zones for fish

RPAs have now created a mechanism to exploit areas which were previously out of casting range and ability of rock and surf anglers. These areas act as refuges from threats for many line fish species, some of which species are exploited. Fishing with RPAs opens these refuge areas to exploitation, thus placing increased pressure on fish populations (Winkler et al. 2021).

With an RPA, there is the ability to target larger individuals, thus making these individuals, which are a cohort of a different life-history stage, vulnerable to targeted exploitation (Cooke et al. 2021), potentially leading to evolutionary effects in fish populations (Jorgensen et al. 2007).

6.2. Physiological stress and injury

Due to the greater distances from the shore, 'fight times' are extended (Winkler et al. 2021), with increased susceptibility to barotrauma, physiological stress, injury and post-capture mortality (Gallagher et al. 2014) if used in a catch-and-release expedition (Gallagher et al. 2014, Winkler et al. 2021). Furthermore, Cooke et al. (2021) also cites an increased incidence of deep-hooking, which is defined by Fobert et al. (2009) as the hook penetrating the oesophagus, stomach, gills, or other vital tissues or organs beyond the mouth cavity under certain conditions using RPAs.

6.3. Additional marine debris in the water

An increased casting distance increases the amount of fishing tackle and line entering the marine environment if the line is broken off and lost (Bruce Mann, pers. comm.[18]). The implications of this has unintended but very real consequences for marine animals. According to Jacks et al. (2001) and O'Toole et al. (2009), the cumulative impacts of the loss of tackle such as sinkers and fishing line on the environment can be considerable.

Abandoned and lost fishing line and hooks in the marine environment are severely under-studied and considered as a neglected category of marine debris, because it's less obvious, small and difficult to sample (Hess et al. 1999; McPhee et al. 2002 and Battisti et al. 2019). However, the impact and effect of fishing lines and fishhooks have been documented extensively for marine turtles (Di Bello et al. 2006; Campani et al. 2013; Barreiros and Raykov 2014; Hoarau et al. 2014; Nicolau et al. 2016), marine mammals (Beck and Barros 1991; van Franeker and Meijboom 2002; Page et al. 2004), seabirds (Cowx 2002; Abraham et al. 2010; Ryan et al. 2016), fish species (Muñoz et al. 2011; Anastasopoulou et al. 2013), and sessile invertebrates (Oliveira et al. 2015).

According to Battisti et al. (2019), fishing lines and hooks may lead to traumatic effects on fauna ranging from abrasions, wounds and subsequent epibiotic infections, starvation, impaired mobility, and increased risk of predation, amputation, strangulation, and death (Chiappone et al. 2005; Criddle et al. 2009; Gregory 2009). Furthermore, rocky habitats together with sessile fauna (molluscs, corals, gorgonians, hydrozoans, bryozoans, sponges etc.) form multi-dimensional and complex habitats, increasing the probability of entanglement (Chiappone et al. 2005; Bauer et al. 2008; Angiolillo et al. 2015). This causes sensitive and fragile fauna, such as gorgonians, erect sponges, corals, and colonial zoanthids to be more vulnerable to fishing lines i.e. breakage and associated ramifications (Angiolillo et al. 2015; Oliveira et al. 2015; Yoshikawa and Asoh 2004). Given the accessibility,

[18]https://www.iol.co.za/sunday-tribune/news/anglers-take-to-the-skies-with-drones-a8733624-1637-435a-acc2-d0e87e9c1106

extensive use and low cost of fishing line and hooks available to recreational fishers, the cumulative effects of this type of marine debris over time can be extremely detrimental to the environment (Macfadyen et al. 2009).

In KZN, it is estimated that 11% of all recorded stranded animals (birds, turtles, seals, dolphins and whales) are a result of marine debris. In 2019, all stranded animals which had been compromised by marine debris was a result of fishing line and hooks (Olbers 2020).

6.4. Impacts on birds

Literature on the effect of RPAs on birds is widely available with studies indicating that some species are may be more sensitive than others (Rummler et al. 2018). In other studies, the use of RPAs as study tools have no/little perceived effect on birds (e.g. Barr et al. 2020; Vas et al. 2015, Chabot & Bird 2015; Chabot et al. 2015; Dulava et al. 2015; Goebel et al. 2015; Weissensteiner et al. 2015; Hodgson et al. 2016; Borrelle & Fletcher 2017). However, RPA-use could impact coastal or marine birds in several ways[19], including:

- disturbance in the vicinity or too close to rookeries, colonies or nests, potentially causing disruption to the breeding success of sensitive bird populations.
- Noise and unfamiliar presence potentially resulting in adult birds moving away from an area, thus leading to neglect or abandonment of eggs and chicks
- territoriality, where birds may perceive an RPA as a threat, leading to an attack on the RPA causing injury or distraction whereby adults neglect their hatchlings, reduce foraging or tending to their own needs;
- a bird which is disturbed while foraging may abandon a good food source and be forced to seek less abundant or nutritious resources; and
- mid-air collisions with birds, causing injuries.

6.5. Drone fishing for sharks

Globally, shark fishing has increased in popularity in the recreational fishery in the last decade (Skomal 2007; Danylchuk et al. 2014). Sharks are generally more susceptible to fishing pressure because of their life-history traits, i.e. slow growing and late maturing (Hoenig and Gruber 1990). According to Gallagher et al. (2017), South Africa is one of the most predominant recreational shark fishing countries in the world. Shark populations are declining worldwide and combined with an increasing angler conservation ethic and growing pressure from environmental advocates; there is a developing trend of recreational anglers converting from shark catch-and-kill to catch-and-release (Gallagher et al. 2017). However, photographic evidence across social media platforms demonstrates that beaches across South Africa continue to be littered with juvenile shark carcasses, which are being dragged up the beaches and left to die or used as bait due to a misconception that the sharks are eating 'their' fish.

In South Africa, Winkler et al. (2021) showed that the drone catch was dominated by large elasmobranchs (97%), with the highest number of catches being the Endangered dusky shark (*Carcharhinus obscurus*) (23%), followed by the Near Threatened bronze whaler shark (*Carcharhinus brachyurus*) (19%), butterfly ray (*Gymnura natalensis*) (13%) and the Critically Endangered whitespotted wedgefish (*Rhynchobatus djiddensis*). Winkler et al. (2021), also noted with concern the very high percentage of IUCN Red Listed species caught by drones in South Africa, making up 69% of the drone fishing catches.

[19]https://www.thespruce.com/birds-and-drones-3571688

The majority of RPA fishing is for the catching of sharks and although illegal in our MPAs, it is a rife practice in both our MPAs as well as along the KZN coastline (Grant Smith, Sharklife, Pers. Comm.) due to no relevant signage, lack of capacity for enforcement and minimal education and awareness campaigns for drone and/shark fishing.

Gallagher et al. (2014) suggested that relying on visual observations of the post-release vitality of sharks (i.e. they are not washing up onto the beaches, therefore they must be surviving) could under-estimate mortality. In South Africa, there is a need for additional research on the levels of mortality and the population-level consequences of fishing mortality for chondrichthyan (shark, ray, skate and chimaera) species. Although the practice of shark catch-and-release only by RPA anglers may be commendable, without data on fishing effort, capture and post-release mortality, the practice is not beneficial for conservation purposes.

Furthermore, in the face of poor shark fishing regulations and associated enforcement and compliance in South Africa, shark conservation and management requires some serious adjustments, as highlighted during the Review of the South African National Plan of Action for the Conservation and Management of Sharks (NPOA-Sharks 2020). In October 2020, the NPOA review panel identified that there needs to be:

- a focus on addressing illegal, unregulated and unreported fishing;
- improved monitoring, surveillance and enforcement; and
- an increased effort to better monitor and manage recreational fisheries, which are currently not monitored and inadequately regulated.

7. User and/or sector conflict

The uncertified use of RPAs in the coastal zone, both for fishing and other recreational purposes, such as photography, is an accident waiting to happen. Eighty-one incidents, near-misses and accidents have been reported world-wide[20], with a mid-air collision of an RPA and an aircraft potentially having dire consequences. In South Africa, there are only three widely known cases on record[21,22,23,] with many most likely being unreported. A number of aviation authorities globally have investigated the potential risks of RPAs to aircraft. The European Cockpit Association[24] published a study on mid-air collisions of RPAs and concluded that:

- helicopter windscreens could be critically damaged by collisions;
- helicopter tail rotors can also be severely damaged;
- whilst more resilient than helicopters, airliner windscreens could be critically damaged by mid-air collisions with 4 kg class quadcopter components, and 3.5 kg class fixed-wing RPAs with exposed metallic components at high, but realistic speeds; and
- an RPA can cause significantly more damage than a bird of equivalent mass at the same speed, due to the hard metallic components.

[20] https://en.wikipedia.org/wiki/List_of_UAV-related_incidents
[21] https://abcnews.go.com/International/drone-crashes-window-hits-mans-head/story?id=38253589
[22] https://www.news24.com/News24/Techno-tussle-at-Mandela-hospital-20130628
[23] https://www.defenceweb.co.za/aerospace/unmanned-aerial-vehicles/suspected-drone-collision-with-aircraft-at-rand-airport/
[24] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/918811/sm all-remotely-piloted-aircraft-systems-drones-mid-air-collision-study.pdf

Despite the South African Consolidated Recreational Angling Association (SACRAA) citing regulations[25] that stated no object or substance shall be released, dispensed, dropped, delivered or deployed from an RPA except by the holder of an RPA Operating Certificate, RPA angling continues to grow among anglers.

In South Africa, drone fishermen argue that drones fly low, are not used to hook and haul fish, but are used as vehicles for bait, not the actual practice of angling. Furthermore, comparisons can be made with remotely controlled bait-boats, which are commonly used by freshwater anglers to drop their baits in distant and inaccessible locations, or to Underwater Drone Fishing[26], a new concept that is becoming popular as the technology becomes more cost-effective. Underwater Drones and remote-controlled bait boats also need to be considered as emerging technological advances in the recreational fishing sector, requiring policies and/or regulations.

To give a perspective of these unregulated technological advances and conflict with other sectors, an incident off La Lucia, KwaZulu-Natal (KZN) took place on 10 June 2020. Various search and rescue entities were alerted to a distress signal by the presence of a green light in the water offshore after sunset. In response, the National Sea Rescue Institute (NSRI), Ethekwini Durban Metro Search and Rescue, South African Police Services (SAPS) Search and Rescue, Ethekwini Lifeguards and various other coastal KZN rescue entities were mobilised to undertake a search during the night. After many hours and various entities taking to the water, the green light was located and found to be a rogue *Aquacat* bait-boat, a remotely-operated vessel used to transport bait through the surf and beyond while being operated from the beach by an angler. A 'rescue' operation such as this has the potential to drain the already-stretched resources from these entities. Unfortunately, without regulations for the use of devices such as these, the Durban Deputy Harbour Master, Captain Justin Adams had no option but to return the device to the owner with a verbal warning.

8. Enforcement and Compliance

While the SACAA has the mandate to ensure safety to persons and property on the ground and all matters relating to civil aviation, their primary focus is that of a regulatory body, meaning they are assigned the task of making the rules, so that South Africa have a fixed set of guidelines by which to implement and enforce aviation safety. The SACAA can also enforce these rules, but only with the assistance of the South African legal system, the SACAA are called upon in court cases and matters relating to aviation as the Authority, but they are not required to enforce the law alone. Law enforcement is provided through enforcement agencies such as public safety departments, traffic departments, environmental management authorities, municipal or metro police, and the SAPS. Given the popularity and use of RPAs in public areas[27] throughout South Africa, it is evident that the law enforcement entities and officers severely lack the training and an understanding of RPA regulations in South Africa.

In terms of the National Environmental Management: Protected Areas Act (NEM:PAA 2004) section 47 which states that it is illegal to fly below 2500 feet above the highest point of any national park, with any aircraft without the express permission of the Management Authority, thereby making protected areas no-fly zones for all unauthorised aircraft systems. Should a person be caught, charged and found guilty for flying a drone in contravention of Section 47 of NEMPAA, they may be liable, to a fine not exceeding R5 million or imprisonment for a period not exceeding five years for a

[25] https://angling-international.com/2021/03/20/drone-fishing-feels-heat-in-south-africa/
[26] Submersibles which can dive and usually fitted with high quality underwater cameras, sonars, bait lines, and sensors for optimal fishing.
[27] https://www.youtube.com/watch?v=KlDRbqq_tVs

first offence as per Section 89 (2), while the penalty for a second offence would be double the first order.

In the Civil Aviation Regulations of 2011, part 185 outlines ‘fines and penalties’ for enforcement for RPA users. However, prosecution of a person using an RPA for their private use for fishing is yet to be tested by law enforcement.

9. Challenges

Using drones for fishing should be viewed as both a fisheries and an environmental and coastal management issue.

One major challenge in regulating fishing / angling with RPAs is that it is rapidly becoming popular among fishermen and a market, although still relatively small, has begun to gain momentum.

Awareness and education that RPAs are strictly regulated for all types of use are severely lacking throughout South Africa. Signage and information for members of the public or tourists, even in Conservation or Protected Areas is still lacking in some provinces. In addition, public areas such as beaches and public parks, even in metropolitan areas is also virtually non-existent.

There is no evidence that any prosecutions, specifically against a private-use RPA operator has ever been tested in court. Arguments by RPA users in public areas include: “there is no signage”, “I’m not disturbing anyone”, “this is a public area, not private property”, “when I purchased my drone, the retailer did not mention that use was restricted or illegal for certain uses” (Durban Metro police, pers. comm.). It can be argued that ‘ignorance of law excuses no one’ [*ignorantia juris non excusat*], whereby a legal principle holds that a person who is unaware of a law, may not escape liability for violating that law merely by being unaware of its content.

10. Conclusion and Recommendations

The sole ownership of the use and management of RPA’s in the coastal zone and marine environment cannot be a ‘Fisheries’ responsibility. The use of RPA’s have extensive implications for other airspace users, beach users, local government, MPA management authorities among others.

However, for the purposes of this report, in accordance with SACAA regulations, and for reasons above, fishing / angling with RPAs in South Africa is an illegal activity which currently lies outside provisions given in the Marine Living Resources Act regulations. Without rapid and proactive promulgation and enforcement, this practice continues to be a growing industry, soon to be argued into a regulated market with consequences to other users of the airspace and the environment.

In early 2021, the Department of Forestry, Fisheries and the Environment (DFFE) confirmed that “drone angling was currently unregulated, but research was being conducted to inform future policy”[28]. In the event of compiling RPA fishing guidelines for South Africa, serious consideration of the SACAA regulations and the environmental impacts should be considered, notwithstanding the minor economic gains to be made through manufacture and ecotourism.

In the interest of both the marine environment and air space safety, it is not recommended that RPA fishing / angling become a permitted activity by DFFE. However, if this activity is to be regulated in South Africa, then it is imperative that an RPA fisherman / angler operates within the current Civil

[28] https://www.iol.co.za/sunday-tribune/news/anglers-take-to-the-skies-with-drones-a8733624-1637-435a-acc2-d0e87e9c1106

Aviation Regulations and is required to possess the necessary RPA operators certification which enable them to operate an RPA with a payload used for releasing, dispensing, dropping, delivering or deploying bait and lures.

Furthermore, the use of drones by disabled people could potentially be regulated and permitted, similar to the process whereby people with disabilities may apply for an Off-Road Vehicle (ORV) exemption so they can access the beach.

It is essential that we all take cognisance that mistakes made on the environment cannot be reversed. Decisions made under pressure by stakeholders could have permanent effects and become inflexible. Anglers, like conservation managers, management authorities and government entities, have a responsibility, not only towards the environment but also to other users.

11. References

- **Abraham ER, Berkenbusch K, Richard Y.** 2010. The capture of seabirds and marine mammals in New Zealand non-commercial fisheries. Ministry of Fisheries. New Zealand Aquatic Environment and Biodiversity Report 64: 1–52
- **Alverson DL, Freeberg MH, Pope JG,Murawski SA.** 1994. A Global Assessment of Fisheries Bycatch and Discards. Rome: Food and Agricultural Organization of the United Nations. FAO Fisheries Technical Paper 339
- **Anastasopoulou A, Mytilineou C, Smith CJ, Papadopoulou KN**. 2013. Plastic debris ingested by deep-water fish of the Ionian Sea (Eastern Mediterranean). Deep Sea Research, Part I: Oceanographic Research Papers 74:11–13
- **Angiolillo, M, Lorenzo B, Farcomeni A, Bo M, Bavestrello G, Santangelo G, Cau A, Mastascusa V, Cau A, Sacco F, Canese S.** 2015. Distribution and assessment of marine debris in the deep Tyrrhenian Sea (NW Mediterranean Sea, Italy). Marine Pollution Bulletin, 92:149–159
- **Arlinghaus R, Cooke SJ, Lyman J, Policansky D, Schwab A, Susk, C, Sutton SG, Thorstad EB.** 2007. Understanding the complexity of catch-and-release in recreational fishing: an integrative synthesis of global knowledge from historical, ethical, social and biological perspectives. Rev. Fish. Sci. 15, 75–167.
- **Barr JR, Green MC, DeMaso SJ, Hardy TB**. 2020. Drone Surveys Do Not Increase Colony-wide Flight Behaviour at Waterbird Nesting Sites, But Sensitivity Varies Among Species. Scientific Reports, 10: 3781.
- **Barreiros JP, Raykov VS.** 2014. Lethal lesions and amputation caused by plastic debris and fishing gear on the loggerhead turtle *caretta caretta* (Linnaeus, 1758). Three case reports from Terceira Island, Azores (NE Atlantic). Marine Pollution Bulletin, 86:518–522.
- **Bartholomew A, Bohnsack JA**. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Reviews in Fish Biology and Fisheries, 15, 129–154.
- **Battisti C, Kroha S, Kozhuharova E, De Michelis S, Fanelli G, Poeta G, Pietrelli, G, Cerfolli F**. 2019. Fishing lines and fish-hooks as neglected marine litter: first data on chemical composition, densities, and biological entrapment from a Mediterranean beach. Environmental Science and Pollution Research, 26: 1000–1007 DOI: https://doi.org/10.1007/s11356-018-3753-9
- **Bauer LJ, Kendall MS, Jeffrey CFG**. 2008. Incidence of marine debris and its relationships with benthic features in Gray's Reef National Marine Sanctuary, Southeast USA. Marine Pollution Bulletin 56:402–413.
- **Beck CA and Barros NB**. 1991. The impact of debris on the Florida manatee. Marine Pollution Bulletin, 22:508–510.
- **Borrelle SB and Fletcher AT.** 2017. Will drones reduce investigator disturbance to surface-nesting seabirds? Marine Ornithology 45: 89–94.
- **Campani T, Baini M, Giannetti M, Cancelli F, Mancusi C, Serena F, Marsili L, Casini S, Fossi MC**. 2013. Presence of plastic debris in loggerhead turtle stranded along the Tuscany coasts of the Pelagos sanctuary for Mediterranean marine mammals (Italy). Marine Pollution Bulletin, 74:225–230.
- **Chabot D and Bird DM.** 2015. Wildlife research and management methods in the 21st century: Where do unmanned aircraft fit in? 1. Journal of Unmanned Vehicle Systems 3: 137-155.
- **Chabot D, Craik SR, and Bird DM.** 2015. Population census of a large common tern colony with a small unmanned aircraft. PloS One 10: e0122588.
- **Chiappone M, Dienes H, Swanson DW, Miller SL.** 2005. Impacts of lost fishing gear on coral reef sessile invertebrates in the Florida Keys National Marine Sanctuary. Biological Conservation, 121:221–230.
- **Coggins LG Jr, Catalano MJ, Allen MS, Pine WE, Walters CJ.** 2007. Effects of cryptic mortality and the hidden costs of using length limits in fishery management. Fish and Fisheries 8(3):196–210
- **Cooke SJ and Cowx IG**. 2004. The role of recreational fishing in global fish crisis. Bioscience, 54(9): 857-859.
- **Cooke SJ and Schramm HL**. 2007. Catch-and-release science and its application to conservation and management of recreational fisheries. Fisheries Management and Ecology, 14:73–79.
- **Cooke SJ, Danylchuk AJ, Danylchuk SE, Suski CD, Goldberg TL.** 2006. Is catch-and-release recreational angling compatible with no-take marine protected areas? Ocean & Coastal Management, 49, 342–354.

- **Cooke SJ, Philipp DP, Dunmall KM, Schreer JF.** 2001. The influence of terminal tackle on injury, handling time and cardiac disturbance of rock bass. North American Journal of Fisheries Management, 21, 333–342.
- **Cooke SJ, Venturelli P, Twardek WM, Lennox RJ, Brownscombe JW, Skov C, Hyder K, Suski CD, Diggles BK, Arlinghaus R, Danylchuk AJ.** 2021. Technological innovations in the recreational fishing sector: implications for fisheries management and policy. Reviews in Fish Biology and Fisheries, https://doi.org/10.1007/s11160-021-09643-1.
- **Cowx IG.** 2002. Recreational fisheries. In: Hart PBJ, Reynolds JD (eds) Handbook of fish biology and fisheries, vol II. Blackwell Science, Oxford, pp 367–390
- **Criddle KR, Amos AF, Carroll P, Coe JM, Donohue MJ, Harris JH, Kim K, MacDonald A, Metcalf K, Rieser A, Young NM**. 2009. Tackling marine debris in the 21st century. The National Academies Press, Washington, DC
- **Danylchuk AJ, Suski, CD, Mandelman JW, Murchie KJ, Haak CR, Brooks AM, Cooke SJ.** 2014. Hooking injury, physiological status and short-term mortality of juvenile lemon sharks (*Negaprion bevirostris*) following catch-and-release recreational angling. Conservation Physiology, 2:cot036.
- **Di Bello A, Valastro C, Staffieri F, Crovace A.** 2006. Contrast radiography of the gastrointestinal tract in sea turtles. Veterinary Radiology and ultrasound, 47:351–354
- **Ditmer MA, Vincent JB, Werden LK, Tanner JC, Laske TG, Laizzo PA, Garshelis DL and Fieberg JR.** 2015. Bears show a physiological but limited behavioural response to Unmanned Aerial Vehicles. Current Biology, 25: 2278 – 2283.
- **Ditton RB, Holland SM, Anderson DK.** 2002. Recreational fishing as tourism. Fisheries 27(3):17–24.
- **Dulava S, Bean WT, Richmond OM.** 2015. Environmental reviews and case studies: applications of unmanned aircraft systems (UAS) for waterbird surveys. Environmental Practice 17: 201-210.
- **FAO (Food and Agricultural Organization of the United Nations).** 2003. State of World Fisheries and Aquaculture 2002. Rome: FAO.
- **Fobert E, Meining P, Colotelo A, O'Connor C, Cooke SJ.** 2009.Cut the line or remove the hook? An evaluation of sublethal and lethal endpoints for deeply hooked bluegill. Fisheries Research, 99: 38-46
- **Froese R, Demirel N, Coro G, Kleisner KM, Winker H.** 2017. Estimating fisheries reference points from catch and resilience. Fish and Fisheries, 18(3):506–526.
- **Gallagher AJ, Hammerschlag N, Danylchuk AJ, Cooke SJ.** 2017. Shark recreational fisheries: Status, challenges, and research needs. Ambio, 46:385–398. DOI 10.1007/s13280-016-0856-8.
- **Gallagher AJ, Serafy JE, Cooke SJ, Hammerschlag N.** 2014. Physiological stress response, reflex impairment, and survival of five sympatric shark species following experimental capture and release. Marine ecology progress series, 496: 207–218. doi: 10.3354/meps10490.
- **Goebel ME, Perryman WL, Hinke JT, Krause DJ, Hann NA, Gardner S, LeRoi DJ**. 2015. A small unmanned aerial system for estimating abundance and size of Antarctic predators. Polar Biology 38: 619-630.
- **Gonçalves J, Henriques R, Alves P, Sousa-Silva R, Monteir AT, Lomba A, Marcos B, Honrado J.** 2016. Evaluating an unmanned aerial vehicle-based approach for assessing habitat extent and condition in fine-scale early successional mountain mosaics. Applied Vegetation Science, 19: 132 – 146.
- **Gregory MR.** 2009. Environmental implications of plastic debris in marine settings–entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philosophical Transactions of the Royal Society, 364:2013–2025
- **Griffiths MH, Attwood CG, Thomson R.** 1999. A new management protocol for the South African Linefishery. In: Mann, B.Q. (ed). Proceedings of the third Southern African Marine Linefish Symposium, Arniston, 28 April -1 May 1999. SANCOR Occasional Report 5: 145-156.
- **Habel JC, Teucher M, Ulrich W, Bauer M, Rödder D**. 2016. Drones for butterfly conservation: larval habitat assessment with an unmanned aerial vehicle. Landscape Ecology, 31: 2385 – 2395.
- **Hess NA, Ribic CA, Vining I.** 1999. Benthic marine debris, with an emphasis on fishery-related items, surrounding Kodiak Island, Alaska, 1994–1996. Marine Pollution Bulletin, 38:885–890

- **Hoarau L, Ainley L, Jean C, Ciccione S**. 2014. Ingestion and defecation of marine debris by loggerhead sea turtles, *Caretta caretta*, from bycatches in the South-West Indian Ocean. Marine Pollution Bulletin, 84:90–96
- **Hodgson A, Kelly N, Peel D.** 2013. Unmanned Aerial Vehicles (UAVs) for surveying marine fauna: a dugong case study. PLoS ONE 8(11): e79556. DOI:10.1371/journal.pone.0079556.
- **Hodgson JC and Koh LP.** 2016. Best practice for minimising unmanned aerial vehicle disturbance to wildlife in biological field research. Current Biology, 26: R404 – R405.
- **Hodgson JC, Baylis SM, Mott R, Herrod A and Clarke RH.** 2016. Precision wildlife monitoring using unmanned aerial vehicles. Scientific Reports 6: 22574.
- **Hoenig JM and Gruber SH.** 1990. Life-history patterns in the elasmobranchs: implications for fisheries management. *In* Elasmobranchs as living resources: advances in the biology, ecology, systematics, and the status of fisheries (H. L. Pratt Jr., S. H. Gruber, and T. Taniuchi, eds.), p. 1–16. NOAA Tech. Rep. NMFS 90.
- **Jacks G, Byström M, Westholm, LJ.** 2001. Lead emissions from lost fishing sinkers. Boreal Environment Research, 6(3): 231–236
- **Jewitt, D and Wijnberg L.** 2018. The use of drones in conservation. Published online by ee Publishers: https://www.ee.co.za/article/the-use-of-drones-in-conservation.html
- **Johnston FD, Beardmore B, Arlinghaus R.** 2015. Optimal management of recreational fisheries in the presence of hooking mortality and noncompliance—predictions from a bioeconomic model incorporating a mechanistic model of angler behavior. Canadian Journal of Fisheries and Aquatic Sciences, 72: 37–53.
- **Jones GP, Pearlstine LG, Percival HF.** 2006. An assessment of small Unmanned Aerial Vehicles for wildlife research. Wildlife Society Bulletin, 34: 750 – 758.
- **Jorgensen C, Enberg K, Dunlop ES, Arlinghaus R, Boukal DS, Brander K, Ernande B, Gardmark A, Johnston F, Matsumura S, Pardoe H, Raab K, Silva A, Vainikka A, Dieckmann, U, Heino M, Rijnsdorp AD.** 2007. Managing evolving fish stocks. Science 318:1247–1248
- **Koh LP and Wich SA**. 2012. Dawn of drone ecology: Low-cost autonomous aerial vehicles for conservation. Tropical Conservation Science, 5: 121 – 132.
- **Macfadyen G, Huntington T, Cappell R.** 2009. Abandoned, lost or otherwise discarded fishing gear. In: UNEP Regional Seas Reports and Studies. UNEP/FAO, Rome, p 115
- **Mann B.Q, Lee B, Cowley PD.** 2016. Growth rate of speckled snapper (Lutjanus rivulatus) based on tag-recapture data from the iSimangaliso Wetland Park, South Africa. African Journal of Marine Science, 38 (1): 111–118.
- **Mann BQ, Cowley PD, Dunlop SW, Potts WM.** 2018. Is catch-and-release shore angling compatible with the conservation goals of marine protected areas? A case study from the iSimangaliso Wetland Park in South Africa. Fisheries Research, 208: 179-188.
- **Mann BQ.** (2013). Southern African Marine Linefish Species Profiles, Oceanographic Research Institute, special publication No. 9, 343pp.
- **McPhee DP, Leadbitter D, Skilleter GA**. 2002. Swallowing the bait: is recreational fishing ecologically sustainable? Pacific Conservation Biology, 8:40–51
- **Muñoz PD, Murillo FJ, Sayago-Gil M, Serrano A, Laporta M, Otero I, Gómez C.** 2011. Effects of deep-sea bottom longlining on the Hatton Bank fish communities and benthic ecosystem, North-East Atlantic. Journal of the Marine Biological Association UK, 91:939–952
- **Muoneke MI, Childress WM.** 1994. Hooking mortality: A review for recreational fisheries. Reviews in Fisheries Science 2: 123–156.
- **Nicolau L, Marçalo A, Ferreira M, Sá S, Vingada J, Eira C**. 2016. Ingestion of marine litter by loggerhead sea turtles, *Caretta caretta*, in Portuguese continental waters. Marine Pollution Bulletin, 103:179–185
- **Nisbet IC & Paul E**. 2004. Ethical issues concerning animal research outside the laboratory. ILAR Journal 45:375-377.
- **O'Toole AC, Hanson KC, Cooke SJ**. 2009. The Effect of Shoreline Recreational Angling Activities on Aquatic and Riparian Habitat Within an Urban Environment: Implications for Conservation and Management. Environmental Management, 44:324–334. DOI: 10.1007/s00267-009-9299-3.

- **Olbers JM.** 2020. Marine Animal Strandings: 2019 Annual Report for KwaZulu-Natal. Ezemvelo KZN Wildlife Internal Report, Pietermaritzburg, South Africa. 36pp
- **Oliveira F, Monteiro P, Bentes L, Henriques NS, Aguilar R, Gonçalves JM**. 2015. Marine litter in the upper São Vicente submarine canyon (SW Portugal): abundance, distribution, composition and fauna interactions. Marine Pollution Bulletin, 97:401–407
- **Page B, McKenzie J, McIntosh R, Baylis A, Morrissey A, Calvert N, Haase T, Berris M, Dowie D, Shaughnessy PD, Goldsworthy SD.** 2004. Entanglement of Australian sea lions and New Zealand fur seals in lost fishing gear and other marine debris before and after government and industry attempts to reduce the problem. Marine Pollution Bulletin, 49:33–42
- **Pollock KH, Pine, WE.** 2007. The design and analysis of field studies to estimate catch-and-release mortality. Fisheries Management and Ecology, 14, 1–8.
- **Raby GD, Packer JR, Danylchuk AJ, Cooke SJ.** 2014. The understudied and underappreciated role of predation in the mortality of fish released from fishing gears. Fish and Fisheries. 15:489–505.
- **Rogers EM.** 1962. Diffusion of innovations. Free Press, New York. p453.
- **Rummler MC, Mustafa O, Maercker J, Peter H, Esefeld J.** 2015. Measuring the influence of unmanned aerial vehicles on Adelie penguins. Polar Biology 39: 1329-1334
- **Rümmler MC, Mustafa O, Maercker J, Peter HU & Esefeld J.** 2018. Sensitivity of Adélie and Gentoo Penguins to various flight activities of a micro UAV. Polar Biology 41, 2481–2493.
- **Ryan PG, de Bruyn PN, Bester, MN**. 2016. Regional differences in plastic ingestion among Southern Ocean fur seals and albatrosses. Marine Pollution Bulletin, 104:207–210
- **Skomal G B.** 2007. Evaluating the physiological and physical consequences of capture on post-release survivorship in large pelagic fishes. Fisheries Management and Ecology, 14:81–89.
- **Tomasso AO, Isley JJ, Tomasso JR**. 1996. Physiological responses and mortality of striped bass angled in freshwater. Transactions of the American Fisheries Society, 125, 321–325.
- **van der Elst RP and de Freitas AJ**. 1988. Long-term trends in Natal marine fisheries. In: Macdonald, IAW, Crawford, R.J.M. (eds). Long-term data series relating to southern Africa's renewable natural resources. South African National Scientific Programme Report 157: 76-83.
- **van Franeker JA, Meijboom A.** 2002. Litter NSV e marine litter monitoring by northern fulmars: a pilot study. ALTERRA-Rapport 401. Alterra, Wageningen, pp 72
- **Vas E, Lescroël, A, Duriez, O, Boguszewski G, Grémillet D.** 2015 Approaching birds with drones: first experiments and ethical guidelines. Biological Letters 11: 20140754.DOI: http://dx.doi.org/10.1098/rsbl.2014.0754.
- **Vermeulen C, Lejeune P, Lisein J, Sawadogo P. and Bouché P**. 2013. Unmanned aerial survey of elephants. PLoS ONE 8(2): e54700. DOI:10.1371/journal.pone.0054700.
- **Weissensteiner MH, Poelstra JW & Wolf JB.** 2015. Low-budget ready-to-fly unmanned aerial vehicles: an effective tool for evaluating the nesting status of canopy-breeding bird species. Journal of Avian Biology 464: 425-430.
- **Whitney NM, White CF, Anderson, PA, Hueter RE, Skomal GB.** 2017. The physiological stress response, post-release behavior, and mortality of blacktip sharks (*Carcharhinus limbatus*) caught on circle and J-hooks in the Florida recreational fishery. Fishery Bulletin, 115:532–543. doi: 10.7755/FB.115.4.9.
- **Winkler AC, Butler EC, Attwood CG, Mann, BQ and WM Potts**. 2021. The emergence of marine recreational drone fishing: Regional trends and emerging concerns. Ambio, https://doi.org/10.1007/s13280-021-01578-y.
- **Will D, Campbell K. and Holmes N.** 2014. Using digital data collection tools to improve overall cost-efficiency and provide timely analysis for decision-making during invasive species eradication campaigns. Wildlife Research, 41: 499 – 509.
- **Yoshikawa T and Asoh K**. 2004. Entanglement of monofilament fishing lines and coral death. Biological Conservation, 117:557–560.