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The Weaponization of Increasingly Autonomous Technologies in the Maritime Environment:

Testing the Waters

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About UNIDIR

The United Nations Institute for Disarmament Research (UNIDIR)—an autonomous institute within the United Nations—conducts research on disarmament and security. UNIDIR is based in Geneva, Switzerland, the centre for bilateral and multilateral disarmament and non-proliferation negotiations, and home of the Conference on Disarmament. The Institute explores current issues pertaining to the variety of existing and future armaments, as well as global diplomacy and local tensions and conflicts. Working with researchers, diplomats, government officials, NGOs and other institutions since 1980, UNIDIR acts as a bridge between the research community and governments. UNIDIR's activities are funded by contributions from governments and donor foundations.

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The Weaponization of Increasingly Autonomous Technologies in the Maritime Environment: Testing the Waters

Recent attention among governments, civil society organizations and the media has focused on technical, military, legal and ethical issues of the weaponization of increasingly autonomous technologies.[1] Experts have suggested that fully autonomous weapons are likely to first appear in the relatively "uncluttered" maritime environment. Yet, policy-makers have directed relatively little attention to the specific issues and challenges in this environment that might be different or more acute than on land or in the air. This paper aims to shed light on these issues in order to inform the broader debate on the weaponization of increasingly autonomous technologies. It is the fourth[2] in a series of UNIDIR papers on this theme.[3]

Context

The marine environment, both on the high seas and underwater, has been the proving ground of many increasingly autonomous technologies. Humans are exploring previously unreachable depths and locations, as well as constructing ever-greater amounts of infrastructure in the marine environment—from deep sea oil rigs to underwater cable networks. Technological advances have permitted development of the tools to do so: robots and systems to help build, maintain, monitor and repair these objects in one of the most physically challenging environments on Earth. Remotely operated at sea and underwater vehicles are already well developed. In the maritime environment—for both the private sector and the military—the restricted

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1 UNIDIR has purposefully chosen to use the word "technologies" in order to encompass the broadest relevant categorization. In this paper, this categorization includes machines (inclusive of robots and weapons) and systems of machines (such as weapon systems), as well as the knowledge practices for designing, organizing and operating them.

2 "Framing Discussions on the Weaponization of Increasingly Autonomous Technologies" (May 2014), "The Weaponization of Increasingly Autonomous Technologies: Considering how Meaningful Human Control Might Move the Discussion Forward" (November 2014), and "The Weaponization of Increasingly Autonomous Technologies: Ethics and Social Values" (March 2015). For more information about UNIDIR's project "The Weaponization of Increasingly Autonomous Technologies", see http://bit.ly/1JSZCc1.

3 The views expressed in this paper are the sole responsibility of UNIDIR. UNIDIR would like to acknowledge the thoughtful contributions of the participants in a May 2014 meeting on maritime autonomy convened by UNIDIR: John Borrie, Maya Brehm, Neil Davison, Kristian Hammond, Peter Herby, Patrick Lin, George Lucas, Noam Lubell, Richard Moyes, Erwan Roche, Lisa Rudnick, WSP Sidhu, Rob Sparrow, Alexandre Vautravers and Kerstin Vignard. Retired Navy Captain Eric Steinmyller (*commissaire en chef de la marine*) provided additional expertise. UNIDIR would also like to acknowledge the contributions of those experts and interviewees who have requested to remain unnamed. Particular thanks are extended to George Lucas for his substantive input and review of this document.

nature of human capacities and related costs render the replacement of manned systems by increasingly autonomous ones very attractive.

In addition, many of the world's conflict flashpoints are on coastal or contested waters. With rising seas, changing weather patterns, and other consequences of global warming, access to previously impassable areas will render the maritime environment an increasingly strategic battle space for an ever-growing number of States.

Experts have suggested that fully autonomous weapon systems are likely to first appear in the relatively "uncluttered" maritime environment.[4] Yet, while a small group of experts are actively considering the legal and ethical issues raised by maritime autonomy,[5] policy-makers have directed little attention to the specific issues and challenges that arise in this context. This paper will consider some of the concerns surrounding the weaponization of increasingly autonomous technologies specific to the marine environment.[6]

Drivers of maritime autonomy

A number of factors have driven the development of sophisticated, increasingly autonomous marine technologies for commercial, scientific and military purposes. There are **environmental factors**: the harshness of the environment related to weather, ocean currents, temperature, underwater pressure and other features as well as the vast areas to be monitored and potentially controlled. **Economic factors** include increasing fuel prices and the high costs of deploying and maintaining human crews at sea for extended periods. The **limits of human personnel**: autonomous technologies are attractive for assignments that humans find physically or mentally unpleasant or unsuitable, such as extended submarine missions. The difficulty or impossibility of maintaining active **communication** with systems operating underwater makes increasingly autonomous operations attractive, particularly when combined with the desire to benefit from the **covert nature** of operating in a communication-denied environment.

Civil applications for increasingly autonomous technologies in the marine environment

Unmanned marine objects have captured the public's imagination, offering a glimpse into a previously unimagined and inaccessible world. While the unmanned devices used by Jacques Cousteau and James Cameron introduced more than one generation to the underwater world, it is now possible for any amateur to buy a small, remotely operated unmanned submersible at relatively low cost.[7]

4 "[S]ome of the most promising future developments in military robotics will likely be realized in the maritime and underwater environment (in surface combat or anti-submarine warfare, for example)…". See George Lucas, Automated Warfare, *Stanford Law & Policy Review*, vol. 25, no 317, pp. 317–340.

5 See, for example, R. Sparrow, "Killer Robots", *Journal of Applied Philosophy*, vol. 24, no. 1, 2007, pp. 62–77; G. Lucas, op. cit.; A. Norris, *Legal Issues Relating to Unmanned Maritime Systems*, US Naval War College Monograph, 2013; W. Matthews, "Murky Waters: Seagoing Drones Swim into New Legal and Ethical Territory", *Defense News*, 9 April 2013; and R. McLaughlin, "Unmanned Naval Vehicles at Sea: USVs, UUVs and the Adequacy of the Law", *Journal of Law, Information & Science*, vol. 21, no. 2, 2012; and B. Berkowitz, "Sea Power in the Robotic Age", *Issues in Science and Technology*, vol. XXX, no. 2, 2014, http://issues.org/30-2/bruce-2/

6 These technologies go by a variety of names, including but not limited to ROVs (remotely operated underwater vehicles), USSVs (Unmanned Sea Surface Vessels), unmanned underwater vehicles (UUVs), and autonomous underwater vehicles (AUVs). This paper predominately highlights the particular challenges of the weaponization of autonomous technologies in the underwater environment as these raise challenges different than those posed on the sea-surface (notably for transparency and communications)—although other challenges, such as the duty to rescue, are particularly pertinent to surface vessels.

7 See, for example, www.rov.org/rov_history.cfm, which uses open-source programming.

No longer limited by a physical tether to a human operator, today increasingly autonomous systems are widely used as unmanned survey platforms, carrying sensors to gather data for a variety of applications (including oceanographic survey, environmental monitoring and sampling, mapping, oil or gas exploration and exploitation, and shipping safety), as well as tasks such as inspection, construction, maintenance, and repair of underwater objects.

Military applications[8] for increasingly autonomous technologies in the maritime environment

A wide range of increasingly autonomous military systems are already deployed in the maritime environment,[9] for a variety of missions including mine-countermeasures, and intelligence, surveillance and reconnaissance (ISR). These systems enable States to monitor activities of interest and potentially hostile actions over areas that could not be easily covered by human operators.

Unmanned surface vehicles can be deployed on missions such as mine-countermeasures, port surveillance, fleet protection and supply delivery. Recent developments in swarming capabilities open realistic possibilities for automated ship protection and area denial, where autonomous surface vessels operate in defensive postures yet could have offensive capabilities.[10] Increasingly autonomous military systems are also of interest for coastal monitoring, anti-piracy and counter-narcotics operations, as well as wide area searches, such as for Malaysian Airlines flight 370.

Operation Iraqi Freedom in 2003 saw the first use of autonomous underwater vehicles for mine warfare operations in Umm Qasr Harbor. Most unmanned underwater systems require some level of autonomy due to the fact that standard methods of navigation such as GPS do not work underwater.

Research is underway to increase autonomous functions for more complex operations. For example, the Defense Advanced Research Projects Agency programme "Anti-Submarine Warfare Continuous Trail Unmanned Vessel" (known as Sea Hunter) attempts to detect and track quiet diesel electric submarines for several months at a time. In order to perform this mission, the system will need to demonstrate several facets of advanced autonomous operation, including "autonomous compliance with maritime laws and conventions for safe navigation, autonomous system management for operational reliability, and autonomous interactions with an intelligent adversary."[11]

Some might be concerned about whether "autonomous interactions" might include selection and engagement of targets. In the specific case of Sea Hunter, US Department of Defense Directive 3000.09 permits semi-autonomous weapon systems that do not "autonomously select and engage individual targets or specific target groups that have not been previously selected by an authorized human operator."[12] However, when considering the intentions of research programmes of other States, it should be noted

8 For a detailed overview of the actual and potential military missions for autonomous technologies in the marine environment, see R. Button et al., 2009, *A Survey of Missions for Unmanned Undersea Vehicles*, RAND.

9 See, for example, United States Department of Defense, *United States Unmanned Systems Integrated Roadmap FY2013–2038*, reference number 14-S-0553, at www.defense.gov/pubs/DOD-USRM-2013.pdf

10 The US Office of Naval Research, for example, successfully tested a "swarm escort" of 13 unmanned surface vessels in 2014. See, for example, S. Freedberg Jr, "Naval Drones 'Swarm', But Who Pulls the Trigger", in *Breaking Defense*, 5 October 2014, breakingdefense.com/2014/10/who-pulls-trigger-for-new-navy-drone-swarm-boats/

11 See www.darpa.mil/Our_Work/TTO/Programs/Anti-Submarine_Warfare_%28ASW%29_Continuous_Trail_Unmanned_Vessel_%28ACTUV%29.aspx; the Sea Wolf prototype, built by Leidos, is under construction and expected to be launched in 2016. See www.navaldrones.com/ACTUV.html.

12 See US DoD Directive 3000.09, 2.c.(1).

that Directive 3000.09 has the advantage of being a public document and one that has received considerable study and scrutiny; few other States have yet to be so forthcoming on their intentions and restrictions on development and use of increasingly autonomous weaponized technologies.

While perhaps not immediately evident, the **weaponization of increasingly autonomous technologies at sea is not new**. Highly automated weapon systems have been deployed at sea for over three decades, such as the Aegis anti-aircraft and anti-ballistic missile systems. Such systems are programmed to detect, track and engage targets that match pre-programmed signatures. At the lowest end of the autonomy spectrum, automatic submarine contact mines have been deployed—and regulated—since the early 20th century.[13] Once deployed, there is no human control of the weapon's location, when it detonates and the selection of the specific target (e.g. this vessel rather than that one) that triggers it. To ensure a minimum level of control, the 1907 Convention Relative to the Laying of Automatic Submarine Contact Mines requires that free floating mines disable themselves within an hour of deployment. Once deployed, mobility is historically a characteristic of concern. However, additional reflection is perhaps needed on how autonomous "uncontrolled" mobility differs from autonomous self-propelling or self-navigating objects.

When considering what sorts of concerns are raised by weaponized autonomy in the maritime environment, it is interesting to contrast the tight regulation of submarine contact mines with that of tethered anti-submarine torpedoes (for example the Mark 60 Captor). Tethered torpedoes have some characteristics of a weapon with considerable autonomy. These weapons are pre-programmed with target signatures (and these signatures are never updated once deployed), lay dormant until an object passes with a matching signature, which activates the torpedo. There is no human "in the loop" at the moment of attack. Is the limited mobility of this system one of the reasons that its deployment has not raised concerns about human control?

As technologies such as sensors improve, the appeal and perceived utility of autonomous weapons for a variety of maritime military operations will increase.[14] For some, increasingly autonomous weapon systems will become attractive in the future for area denial missions, such as along extended coastlines or on patrol in "exclusion zones" at sea. Weaponization might also be motivated by a desire to equip the ISR systems mentioned above with means to defend against attack, or even to patrol and defend critical underwater infrastructure.

Observations

How "uncluttered" is the marine environment and does it matter?

Deployment of nascent weaponized autonomous technologies in a so-called "uncluttered environment" is viewed by some as a relatively low risk and uncontroversial place to "test the waters" for increasingly autonomous weaponized systems. One of the greatest attractions of doing so is the claim that there are relative few civilians and civilian objects in this "uncluttered" setting, and thus this is a less risky environment for development,

13 1907 Convention Relative to the Laying of Automatic Submarine Contact Mines.

14 For example, the US has articulated a long-term vision for military AUV applications, despite that many of these are not yet feasible with existing technology. See, for example, the US Navy's UUV Master Plan (US Navy, 2004), which lays out a fifty-year vision of military AUV applications, and the Office of the Secretary of Defense's Unmanned Systems Roadmap 2007–2032 (OSD, 2007).

testing and deployment. Yet, to what degree is this characterization of the maritime environment accurate?

Perhaps it would be useful to consider another critically strategic and "uncluttered" environment—outer space. Like the planet's oceans, outer space is vast and relatively empty. But like the oceans, there are small areas that are extremely crowded or strategically important for both military and civilian applications—such as low-Earth orbit and geo-synchronous orbit.

In the absence of regulation, increasingly autonomous technologies will likely be found in both the relatively empty as well as more cluttered areas of the marine environment. While the majority of the world's marine environment is in fact devoid of civil or military objects or humans, one must consider that the most strategic parts will be crowded or contested—consider the Red Sea[15] or the areas around disputed islands in the South and East China Seas. The resource-rich Arctic is another place to watch: with an eighth of the world's oil and a quarter of its gas resources, melting ice has made this region more accessible and attractive to exploit. For example, in December 2014, Denmark registered a claim with the UN Convention on the Law of the Sea (UNCLOS) for 900,000km^2 of Arctic seabed—a claim that likely conflicts with those of both Russia and Canada.

In addition, unmanned and increasingly autonomous systems will permit deployment of ever greater numbers of maritime objects. This increasing mix of both civilian and military objects and infrastructures will certainly make the marine environment both more complex and crowded. Thus, policy makers should be cautious about basing their considerations on generalizations or assumptions that the maritime environment will remain as "uncluttered" as today.

Lastly, the marine environment is not homogeneous. The operation of increasingly autonomous technologies on the high seas, in territorial or littoral waters, and in Exclusive Economic Zones will need to take into account the different permitted activities and operational rules and legal regimes that apply.

Autonomy in a communication-denied environment

Limited communication is one of the oldest challenges in naval warfare, one that historically required that naval commanders be given a high degree of autonomy in carrying out their missions. Technological advances such as satellites have improved both situational awareness and communication at sea.

Underwater communication remains challenging. Autonomous technologies will make possible "lay and wait" (so-called "long-loiter") missions of hitherto unimagined duration. In extended time frames much can change; political objectives or military strategies might evolve, or a conflict might end. Changing circumstances in combination with limited or no communication links seems to be a particularly problematic combination. How will adequate command responsibility be exercised over these technologies and how might such control be verified? In a communication-denied environment, how would one know if a system were functioning as designed and desired, or not subject to interference?

Technologies for undersea communications are improving, but for now these function in limited ranges. Thus while some of the communication issues are likely to be resolved over

15 For example, sea-bed mining exploration is occurring in the Atlantis II Deep basin of the Red Sea. See www.globaloceancommission.org/wp-content/uploads/GOC-paper05-seabed-mining.pdf.

time as technologies continue to improve, for more ambitious missions (such as extended "lay and wait" or long-distance tracking) communication is likely to remain challenging for the near future.

To some, autonomy is particularly attractive in the undersea environment due to the **difficulty of ensuring real-time communications** as well as the **undesirability of communications** altogether. This can be summarized as whether communications are possible versus whether communications are desirable. Setting aside the technological challenges to underwater communication, it is the latter that presents the greatest paradox about the utility of weaponizing increasingly autonomous maritime technologies. Limiting communications has advantages for secrecy and stealth, and reduces opportunities for jamming, disruption or take-over of the system. Thus minimizing communications is a means of limiting an adversary's opportunities to detect or interfere with one's operations. However, minimal or no communications also limits the opportunity for mission updates or status monitoring, as well as locating and tracking one's own objects—all of which would be crucial for ensuring compliance with international humanitarian law (IHL), accountability frameworks and adapting to changing orders and circumstances. One might say that the greatest strategic utility of maritime autonomous technologies is ultimately the factor of greatest concern.

What's in a name? Is it a vessel, a weapon or something else altogether?

Just as terminology surrounding basic concepts, such as autonomy itself, remains unclear at the early stages of the international discussion,[16] the terminology used to describe these marine systems can have a decisive impact on how one thinks about them in legal terms.

The legal regime applying to armed conflict at sea remains less elaborate than that governing land warfare. While the basic rules of IHL, namely those on distinction, proportionality and precautions in attack undisputedly apply, there is comparatively little treaty law[17] specifically addressing the challenges of doing so at sea.

There are two existing categories of objects in maritime law relevant to discussions of increasing marine autonomy: **vessels** and **weapons**. The distinction is crucial in determining which rules and responsibilities would apply to the deployment and use of increasingly autonomous weaponized maritime technologies.

It is important to note that existing law relevant to armed conflict at sea is primarily built around the concept of a **vessel**, such as a ship, submarine, landing craft, etc.

Vessels are subject to a range of rules and responsibilities under international law. These include:

- The responsibility to search for and assist wounded, sick and shipwrecked persons after an engagement,
- To search for persons reported missing by one's opponent, and

16 See UNIDIR, "Framing Discussions on the Weaponization of Increasingly Autonomous Technologies", op cit.
17 Relevant treaties include the: 1907 Hague Convention (VIII) relative to the Laying of Automatic Submarine Contact Mines, 1907 Hague Convention (IX) concerning Bombardment by Naval Forces in Time of War, 1907 Hague Convention (X) for the Adaptation to Maritime Warfare of the Principles of the Geneva Convention, 1949 Geneva Convention II for the amelioration of the condition of wounded, sick and shipwrecked members of armed forces at sea and the 1982 Convention on the Law of the Sea. An authoritative modern summary of applicable law by international lawyers and naval experts based on current State practice is contained in the 1994 San Remo Manual on International Law Applicable to Armed Conflicts at Sea.

- To respect and provide quarter to an enemy vessel that has signalled its intention to surrender.

There are also protections afforded to specific types of vessels.[18] Combatant vessels are obliged to respect the ships of neutral countries, as well as hospital and scientific ships and those carrying civilians. Under certain conditions, a State may shift the responsibility for avoiding harm to vessels not involved in the conflict by declaring an "exclusion zone" for such vessels.

It is already possible to distinguish between enemy warships and protected vessels on the high seas to a high degree of certainty. Systems operating in the submarine environment can render a distinction based on the detection of acoustic signals that provide information on the type of ship involved, its speed and direction based on known acoustic "signatures" for particular types of ships.[19] It is less clear, however, whether this high degree of distinction can be maintained in more congested waters where a variety of objects may be operating simultaneously or as new autonomous marine objects proliferate faster than signatures are catalogued.

However, it is unlikely that weaponized autonomous technologies would be able to fulfil the obligations set out in two of the bullet points above given that they are not likely to be designed for search and rescue operations. Requiring the capability to be able to perform rescue would undermine some of the advantages of unmanned systems as they would need to be designed to handle limited manned operations as well. Additionally, there remain significant technological challenges to ensuring that sensors have the ability to detect the variety of ways a ship can signal its intent to surrender.

A second way of describing a fully autonomous surface or submarine system capable of attacking an opponent's vessels is to consider it a **weapon**. Categorizing these objects as weapons clarifies that they are deployed by humans who are responsible for their use in compliance with existing legal frameworks. Nevertheless, the same concerns arise here with autonomous weapons as in other environments, such as land or air, regarding the system's capacity to discriminate, to judge the proportionality of an attack and to take feasible precautions to protect civilians. In addition, autonomous marine weapon systems would also need to be capable to respect freedom of navigation on the high seas in accordance with general obligations of international law. While arguably more technologically sophisticated than free-floating mines (which are highly regulated in large part due to the hazard they pose to freedom of navigation), would autonomous maritime weapons be perceived as posing a significantly lower risk of accidental detonation?

Does the weaponization of increasingly autonomous technologies in the maritime environment require the development of a fundamentally new set of categories, concepts and rules? Just as Special Rapporteur Christof Heyns has warned that the weaponization of increasingly autonomous systems might one day blur the distinction between weapon and soldier, in a weaponized autonomous marine object the vessel or platform, the weapon and the soldier could become one.[20]

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18 See, for example, A. Norris op. cit.

19 However, signatures are not necessarily static: for example, they can evolve and change as a ship's parts wear, are refitted or are refurbished.

20 Thanks to the presentations and explanations offered by invited experts Rob Sparrow and George Lucas on the vehicle–weapon distinction.

Consideration of precedents—placing limits on time and space?

Are there particular challenges posed by technologically sophisticated weaponized objects in a communication-denied environment and how are these challenges different when the object is mobile/self-propelling, free-floating or fixed? As mentioned above, the 1907 Convention Relative to the Laying of Automatic Submarine Contact Mines places tight time limitations on free-floating weapons—they are not to function for longer than one hour after deployment. No such limitation of active life is placed on anchored sea mines or tethered systems like the Mark Captor 60. If these objects are categorized as weapons, further consideration of the legal precedents on how mobility and the time dimension interact (such as in long-loiter missions) is necessary.[21]

Risks and policy considerations

In addition to the observations mentioned above, several other points specific to the weaponization of increasingly autonomous marine technologies bear consideration.

a) **Diffusion into new environments**—Systems designed for the maritime environment may be used in a range of other environments over time and may be used for applications other than those originally foreseen. Unmanned aerial vehicles (UAVs) were developed first for ISR missions, but within years were being used for armed missions as well. Already, at least one highly automated system originally designed for maritime use has been reconfigured for land-based applications.[22] Once tested, proven and considered "acceptable" in the marine environment, these technologies might migrate into other contexts. In this regard, High Contracting Parties to Additional Protocol I of the Geneva Conventions have an obligation to determine whether the employment of a new weapon, means or method of warfare is sufficiently tested to know "whether its employment would, in some or all circumstances, be prohibited".[23]

b) **Increasing actors and objects in the maritime environment**—Increased international commerce, potential exploitation of the seabed for resources and the opening of previously frozen sea areas will lead to greater use of the seas by a variety of commercial actors and States. The nature of seagoing objects—both civilian and military—is rapidly evolving. As these numbers increase, keeping the signature databases used for monitoring, tracking and targeting up-to-date will pose a larger challenge than it does today—both in terms of adding new signatures as well as updating the signature catalogue programmed in objects already deployed in a communication-denied environment.

c) **Accidental attacks and unintended interactions**—Mechanical failures, malfunctions or mistakes are inevitable. When these unfortunately occur, will the fact that the system was operating autonomously create greater tensions? Will it be an accident that ultimately tests the robustness of existing accountability frameworks?

21 This legal precedence is only relevant if the loitering object is considered a weapon, rather than a vessel.
22 The Aegis anti-aircraft/missile system. See www.strategypage.com/htmw/htada/20140304.aspx
23 See Article 36 of Protocol Additional to the Geneva Conventions of 12 August 1949, and relating to the Protection of Victims of International Armed Conflicts (Protocol I), 8 June 1977.

The deployment of a highly autonomous system outside of communication range and outside of an active conflict could lead to an accidental attack on or collision with a military object of another country. Although the object might be a legitimate target in wartime, an unintended attack in peacetime or in a period of tension could trigger retaliation, escalation and incite a broader conflict.

In addition, considering that around 90% of global trade is carried out by maritime shipping,[24] States will need to consider industry and commerce as important stakeholders in the consideration of weaponized autonomous maritime objects. An accidental attack on a civilian vessel by an autonomous technology might alter public perception of the reliability and safety of these systems as well as whether they are an impediment to freedom of navigation.

d) **Proliferation flashpoints**—The deployment of increasingly sophisticated autonomous technologies might be perceived as more threatening than the deployment of manned vessels; perhaps because it seems to put less at risk for the deploying military, coupled with the perception that due to the lower risk to its own forces, they might engage in riskier or more belligerent behaviour. In addition, unlike, for example, terrestrial manoeuvres or satellite launches, which are relatively easy to observe via a variety of human and technical means, underwater deployment and operations are characterized by significantly less transparency, which could destabilize relations in situations of tension.

e) **Environmental protection**—Increasingly autonomous systems operating for extended time spans in remote areas will require a long-lasting energy source. Systems with low manoeuvrability require significantly less energy and considerable research is underway on sustainable energy sources such as harnessing ocean currents. Highly manoeuvrable systems will require significant energy resources from batteries, diesel or gas.

The UN Convention on the Law of the Sea notes the requirement that States Parties "protect and preserve the marine environment", as well as "take measures to prevent, reduce, and control marine pollution from any source".[25] More generally, States have the obligation to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or areas otherwise beyond the limits of its national jurisdiction.[26]

An important consideration is what will happen to autonomous weaponized maritime objects at the end of their active life. Will there be an obligation for a State to recuperate them when their missions are completed? Depending on their energy source and payload, are there environmental concerns that arise from malfunctioning or unrecoverable objects? Due to the potential for catastrophic

24 See the International Chamber of Shipping, www.ics-shipping.org/shipping-facts/shipping-and-world-trade.

25 United Nations Convention on the Law of the Sea, articles 192 and 194. Even though Article 236 explicitly states that 'any warship, naval auxiliary, other vessels or aircraft', parties are instructed to 'ensure, by the adoption of appropriate measures not impairing operations or operational capabilities … that such vessels or aircraft act in a manner consistent, so far as is reasonable and practicable, with this Convention'. See M. Bothe et al., "International law protecting the Environment during armed conflict: gaps and opportunities", *International Review of the Red Cross*, vol. 92, no. 879, 2010, pp. 569–92.

26 See, for example, 1996 Advisory Opinion on the Legality of the Threat or Use of Nuclear Weapons, para 29; and the Declaration of the United Nations Conference on the Human Environment (Stockholm Declaration) of 1972, Principle 21.

environmental consequences, as a precautionary measure, should autonomous nuclear-powered marine objects be pre-emptively banned?

Even if an autonomous system were able to allay all of the concerns and challenges mentioned above, a range of risks and policy issues would remain. While these are not unique to the maritime environment, they are worthy of mention here as maritime autonomy is developing so quickly.

a) **Quality control issues**—Once autonomous weapon systems are deployed by one State, others with the capacity to produce them are likely to follow suit. Not all countries have the same technological capabilities and thus these might not be "state of the art" systems with the same technological sophistication or precision.[27] Therefore, policy discussions focused solely on the most technologically advanced capacities may lead to a false sense of security at best or be misleading at worst.

b) **Cycle of measures and countermeasures**—A wide range of countermeasures can be conceived for "hijacking", or interfering with, increasingly autonomous systems. As seen throughout history with other technological advances in warfare, a cycle of measures and counter-measures can be expected that will require continuous investment and improvement of the systems. The more autonomous and sophisticated the system, the more the system will rely on its software—which will be a critical point of vulnerability. Will the weaponization of increasing autonomous technologies fuel cyber operations to exploit such vulnerabilities?[28]

c) **Control of "dual-use" technologies**—Increasingly autonomous technologies are evolving at a rapid pace—and the civilian and commercial applications are of broad interest to a wide range of countries and industrial sectors. In the absence of any agreed rules regulating the use of these technologies for weapon purposes, some might suggest controls on "dual-use" technologies. Others fear that control regimes might hinder scientific research on civilian applications of autonomy and therefore economic development. This is of particular concern to science and industry as they are already dependent on unmanned technologies with some level of autonomy in the marine environment.

Conclusions

A review of the challenges arising from the weaponization of increasingly autonomous technologies in the maritime environment suggests that, even in this relatively "uncomplicated" environment, a range of fundamental issues need to be considered, addressed and resolved. In particular, the risks of deploying increasingly autonomous weaponized systems in the underwater environment where communication is difficult or impossible for extended periods of time requires much deeper reflection and discussion—particularly in light of some States' concerns about the importance of Meaningful Human Control.[29]

Far from being a marginal part of current international discussions, autonomy in the marine environment is a practical case study for international policy discussions on weapons and

27 Less than state-of-the-art systems might be a product of original R&D or through reverse engineering of a captured system.
28 Subject of a future UNIDIR paper.
29 See UNIDIR, "The Weaponization of Increasingly Autonomous Technologies: Considering how Meaningful Human Control Might Move the Discussion Forward" (November 2014).

autonomy. These **technologies are well advanced**, not futuristic scenarios. There is a wide group of **stakeholders**: not just the military, but also a variety of industries and scientific communities. The current technological **limitations on communications** underwater offer a concrete opportunity to consider what level of comfort States have with weaponized objects operating outside of real-time human control. Lastly, underwater activities are more difficult to observe than those on the surface, on land or in the air, and therefore invite consideration of what levels and types of **transparency** would be necessary or desirable for increasingly autonomous weaponized technologies.

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