## 1AC TOC

### 1AC: Plan

#### Plan - Private entities ought not appropriate lunar heritage sites in outer space.

* We will defend NASA’s interpretation of lunar heritage sites

Harrington 19, Andrea J. "Preserving Humanity's Heritage in Space: Fifty Years after Apollo 11 and beyond." J. Air L. & Com. 84 (2019): 299. (Associate Professor and Director of the Schriever Space Scholars at USAF Air Command and Staff College)//Elmer

The issue of humanity’s cultural heritage in space has arisen as one of many unanswered questions in space law, with no international agreements specifically addressing it. With the beginning of the space age fifty-six years ago and a series of remarkable achievements in space exploration behind us, it is necessary to determine what should be done regarding the “artifacts” of this exploration. NASA has promulgated their recommendations for spacefaring entities with the goal of protecting the lunar artifacts left behind by the Apollo missions.8 These recommendations establish “keep-out zones” of up to a four kilometer diameter with the aim of protecting the artifacts, particularly from dangerous, fastmoving particles that arise as a result of craft landings.9 Experience has shown that even artifacts that are sheltered by craters can be significantly sandblasted and pitted as a result of the moving particles.10 These recommendations, supposedly drafted in conformity with the Outer Space Treaty, however, are completely nonbinding.11 Legislation that has passed the U.S. Senate and is under consideration by the House of Representatives as of July 2019 would make these recommendations binding on U.S. entities seeking to land on the Moon.12 Accidental damage from unrelated missions, however, is only one of many threats to space artifacts. With the impending return to the Moon, it is likely that individuals and corporations will be looking to turn a profit from space heritage, without concern for the protection of such heritage. Tourists may disrupt sites with careless expeditions and landing sites may be desecrated so that the items can be sold. A Russian Lunakhod lunar rover has already been sold at auction to a private party, though it has not yet been moved from its original position on the Moon.13 While national heritage legislation can protect space artifacts from citizens of their own countries, there is currently no effective means in the present space law regime by which a country can protect its heritage from other countries.14 Both California and New Mexico have added Tranquility Base to their list of protected heritage sites.15 However, this solution, and those proposed in the bill put forth to the U.S. House of Representatives, only serve to restrict the activities of a small subset of the potential visitors to the Moon. Though the Senate bill calls for the President to initiate negotiations for a binding international agreement, there is still a long road from this bill to a potential agreement.16 A solution is needed to prevent the damage, destruction, loss, or private appropriation of our cultural heritage in space.

### 1AC: Lunar Heritage

#### The Advantage is Lunar Heritage:

#### Global Moon Rush by private actors is coming now.

Sample 19 Ian Sample 7-19-2019 “Apollo 11 site should be granted heritage status, says space agency boss” <https://www.theguardian.com/science/2019/jul/19/apollo-11-site-heritage-status-space-agency-moon> (PhD at Queens Mary College)//Elmer

But protecting lunar heritage may not be straightforward. On Earth, the United Nations Educational, Scientific and Cultural Organisation (Unesco) decides what deserves world heritage status from nominations sent by countries that claim ownership of the sites. Different rules apply in space. The UN’s outer space treaty, a keystone of space law, states that all countries are free to explore and use space, but warns it “is not subject to national appropriation by claim of sovereignty”. In other words, space is for all and owned by none. Wörner is not put off and sees no need for troublesome regulations. “My hope is that humanity is smart enough not to go back to this type of earthly protection. Just protect it. That’s enough. Just protect it and have everybody agree,” he said. A no-go zone of 50 metres around Tranquility base should do the job, he added. Martin Rees, the Cambridge cosmologist and astronomer royal, said there was a case for designating the sites so future generations and explorers were aware of their importance. “If there are any artefacts there, they shouldn’t be purloined,” he said. “Probably orbiting spacecraft will provide routine CCTV-style coverage which would prevent this from being done clandestinely.” Beyond the dust-covered hardware that stands motionless on the moon, Lord Rees suspects future activity could drive calls for broader lunar protection. The Apollo 17 astronaut and geologist Harrison Schmidt has advocated strip mining the moon for helium-3, a potential source of energy. The proposal, which Rees suggests has raised eyebrows in the community, could potentially provoke a backlash. “There might be pressure to preserve the more attractive moonscapes against such despoilation, and to try to enforce regulations as in the Antarctic,” he said. Fifty years on from Apollo 11, the moon is still a place to make statements. In January, the Chinese space agency became the first to land a probe on the far side. On Monday, India hopes to launch a robotic probe, the delayed Chandrayaan-2 lander that is bound for the unchartered lunar south pole. Far more is on the cards. Major space agencies, including ESA and Nasa, plan a “lunar gateway”, described by Wörner as a “bus stop to the moon and beyond”. His vision is for a “moon village”, but rather than a sprawl of domes, shops and a cosy pub, it is more an agreement between nations and industry to cooperate on lunar projects. The private sector is eager to be involved. Between now and 2024, at least five companies aim to launch lunar landers. In May, Nasa selected three companies to design, build and operate spacecraft that will ferry scientific experiments and technology packages to the moon. The coming flurry of activity may make protection more urgent. Michelle Hanlon, a space lawyer at the University of Mississippi, co-founded the non-profit organisation For all Moonkind to protect, preserve and memorialise human heritage on the moon. While she conceded that not all of the sites that bear evidence of human activity needed protection, she said many held invaluable scientific and archaeological data that we could not afford to lose. “These sites need to be protected from disruption if only for that reason,” she added. The protection should be far wider, and more formal, than Wörner calls for, Hanlon argues. “It is astounding to me that we wouldn’t protect the site of Luna 2, the very first object humans crashed on to another celestial body, and Luna 9, the very first object humans soft-landed on another celestial body,” she said. The Soviet Luna programme sent robotic craft to the moon between 1959 and 1976. “The director general has a much more optimistic view of human nature than I do,” Hanlon said. “I completely agree that the entities and nations headed back to the moon in the near future will take a commonsense approach and give due regard to the sites and artefacts. However, that is the near future. We have to be prepared for the company or nation that doesn’t care. Or worse, that seeks to return to the moon primarily to pillage for artefacts that will undoubtedly sell for tremendous amounts of money here on Earth.”

#### Corporate development, tourism, and looting will destroy scientifically rich Tranquility base artifacts.

Fessl 19 Sophie Fessl 7-10-2019 “Should the Moon Landing Site Be a National Historic Landmark?” <https://daily.jstor.org/should-the-moon-landing-site-be-a-national-historic-landmark/> (PhD King’s College London, BA Oxford)//Elmer

When Neil Armstrong set foot on the moon on July 20, 1969, the pictures sent to Earth captured a historical moment: It was the first time that any human set foot on another body in our solar system. Fifty years later, experts are debating how to preserve humankind’s first steps beyond Earth. Could a National Park on the moon be the solution to saving Armstrong’s bootprints for future archaeologists? Flags, rovers, laser-reflecting mirrors, footprint—these are just a few of the dozens of artifacts and features that bear witness to our exploration of the moon. Archaeologists argue that these objects are a record to trace the development of humans in space. “Surely, those footprints are as important as those left by hominids at Laetoli, Tanzania, in the story of human development,” the anthropologist P.J. Capelotti wrote in Archaeology. While the oldest then known examples of hominins walking on two feet were cemented in ash 3.6 million years ago, “those at Tranquility Base could be swept away with a casual brush of a space tourist’s hand.” Fragile Traces Just how fragile humankind’s lunar traces are was seen already during Apollo 12. On November 19, 1969, Charles “Pete” Conrad and Alan Bean manually landed their lunar module in the moon’s Ocean of Storms, 200 meters from the unmanned probe Surveyor 3, which was left sitting on the moon’s surface two years earlier, in 1967. The next day, Conrad and Bean hopped to Surveyor 3. As they approached the spacecraft, they were surprised: The spacecraft, originally bright white, had turned light brown. It was covered in a fine layer of moon dust, likely kicked up by their landing. Harsh ultraviolet light has likely bleached the U.S. flag bright white. Without Apollo 12 upsetting the moon dust, Surveyor 3 would likely have remained stark white. Unlike Earth, the moon has no wind that carries away the dust, no rain to corrode materials, and no plate tectonic activity to pull sites on the surface back into the moon. But the moon’s thin atmosphere also means that solar wind particles bombard the lunar surface, and harsh ultraviolet light has likely bleached the U.S. flag bright white. The astronauts’ first bootprints will likely be on the moon for a long time, and will almost certainly still be there when humans next visit—unless, by tragic coincidence, a meteorite hits them first. Had LunaCorp not abandoned the idea in the early 2000s, the company’s plan to send a robot to visit the most famous sites of moon exploration could have done a lot of damage. And with Jeff Bezos’ recent unveiling of a mock-up of the lunar lander Blue Moon, it is only a matter of time before corporate adventurers and space tourists reach the moon. Historians and archaeologists are keen to avoid lunar looting. Roger Launius, senior curator of space history at the National Air and Space Museum in Washington, D.C., warned: “What we don’t want to happen is what happened in Antarctica at Scott’s hut. People took souvenirs, and nothing was done to try to preserve those until fairly late in the game.” On the other hand, there is a legitimate scientific interest in investigating how the equipment that’s on the moon was affected by a decades-long stay there.

#### Private entities are a unique threat---universal rules key.

* Private Key Card – AT: Alt Causes
* AT: Unilat CP
* AT: Adv CP
* AT: Generic DA
* AT: OST DA

Hertzfeld and Pace 13 (, H. and Pace, S., 2013. International Cooperation on Human Lunar Heritage. [online] Cpb-us-e1.wpmucdn.com. Available at: <https://cpb-us-e1.wpmucdn.com/blogs.gwu.edu/dist/7/314/files/2018/10/Hertzfeld-and-Pace-International-Cooperation-on-Human-Lunar-Heritage-t984sx.pdf> [Accessed 18 January 2022] Dr. Hertzfeld is an expert in the economic, legal, and policy issues of space and advanced technological development. Dr. Hertzfeld holds a B.A. from the University of Pennsylvania, an M.A. from Washington University, and a Ph.D. degree in economics from Temple University. He also holds a J.D. degree from the George Washington University and is a member of the Bar in Pennsylvania and the District of Columbia. Dr. Hertzfeld joined the Space Policy Institute in 1992. His research projects have included studies on the privatization of the Space Shuttle, the economic benefits of NASA R&D expenditures, and the socioeconomic impacts of earth observation technologies. He teaches a course in Space Law and a course in microeconomics through the Economics Department at G.W. Dr. Hertzfeld has served as a Senior Economist and Policy Analyst at both NASA and the National Science Foundation, and has been a consultant to many U.S. and international organizations, including a recent project on space applications with the OECD. He is the co-editor of Space Economics (AIAA 1992). Selected other publications include a study of the issues for privatizing the Space Shuttle (2000), an analysis of the value of information from better weather forecasts, an analysis of sovereignty and property rights published in the Journal of International Law (University of Chicago, 2005), and an economic analysis of the space launch vehicle industry (2005). Dr. Hertzfeld has also edited and prepared a new edition of the Study Guide and Case Book for Managerial Economics (Sixth Edition, W.W. Norton & Co.). Dr. Scott N. Pace is the Deputy Assistant to the President and Executive Secretary of the National Space Council (NSpC). He joined the NSpC in August 2017. From 2008-2017, he was the Director of the Space Policy Institute and a Professor of the Practice of International Affairs at George Washington University’s Elliott School of International Affairs. From 2005-2008, he served as the Associate Administrator for Program Analysis and Evaluation at NASA. Prior to NASA, he was the Assistant Director for Space and Aeronautics in the White House Office of Science and Technology Policy. From 1993-2000, he worked for the RAND Corporation’s Science and Technology Policy Institute, and from 1990-1993, he served as the Deputy Director and Acting Director of the Office of Space Commerce, in the Office of the Deputy Secretary of the Department of Commerce. In 1980, he received a Bachelor of Science degree in Physics from Harvey Mudd College; in 1982, Masters degrees in Aeronautics & Astronautics and Technology & Policy from the Massachusetts Institute of Technology; and in 1989, a Doctorate in Policy Analysis from the RAND Graduate School.)-rahulpenu

International Cooperation on Human Lunar Heritage The U.S. Apollo Space Program was a premier technological accomplishment of the 20th century. Preserving the six historic landing sites of the manned Apollo missions, as well as the mementos and equipment still on the Moon from those and other U.S. (e.g., Ranger and Surveyor) and Soviet Union (e.g., Luna) missions is important. Some of the instruments on the lunar surface are still active, monitored, and provide valuable scientifi c information. But recent government and **private**-**sector** **plans** to explore and potentially use lunar resources for commercial activity raise questions about the use of the Moon and potential accidental or purposeful threats to the historic sites and scientific equipment there. Although some steps to protect these sites have been proposed, we suggest a better way, drawing on international, not U.S. unilateral, recognition for the sites. Less than 2 years before the fi rst footsteps on the lunar surface on 20 July 1969 (see the image) , the United Nations Outer Space Treaty (OST) was drafted, ratifi ed, and came into force ( 1). Article II of the OST reinforced and formalized the international standard that outer space, the Moon, and other celestial bodies would not be subject to claims of sovereignty from any nation by any means, including appropriation. The OST prohibits ownership of territory or its appropriation by any state party to the treaty, which includes the United States, Russia, and 126 other nations. It does not prohibit the use of the Moon and its resources. In fact, the treaty emphasizes the importance of freedom of access to space for any nation and the importance of international cooperation in space exploration. These principles of the space treaties have enabled gains in science and technology and have contributed to international stability in space. New attention is being focused on the lunar surface. China has an active Moon exploration program and is considering sending astronauts (taikonauts) to the Moon. **Private** **firms** are contemplating robotic **missions** that could land in the vicinity of the historical sites of Apollo and other missions. Although we might assume the best of intentions for such missions, they could **irreparably** **disturb** the **traces** **of** the first **human** **visits** to another world. NASA has taken **steps** **to** **protect** the lunar landing **sites** and equipment and to initiate a process to create recognized norms of behavior. In July 2011, guidelines were issued for private companies competing in the Google Lunar X Prize that established detailed requirements for avoiding damage to U.S. government property on the Moon ( 2). H.R. 2617, The Apollo Lunar Landing Legacy Act, was introduced into the U.S. Congress on 8 July 2013 ( 3). In essence, it proposes to designate the Apollo landing sites and U.S. equipment on the Moon as a U.S. National Park with jurisdiction under the auspices of the U.S. Department of the Interior. Although the bill acknowledges treaty obligations of the United States, it would create, in effect, a unilateral U.S. action to control parts of the Moon. This would **create** a **direct** **conflict** **with** **i**nternational **law** and could be viewed as a **violation** **of** U.S. commitments under the **OST**. It would be an ineffective way of protecting historical U.S. sites, and it fails to address interests of other states that have visited and will likely visit the Moon. It is **legally** **flawed**, **unenforceable**, and **contradictory** **to** our national **space** **policy** and our international relations in space ( 4). There is a better way for the United States to protect its historic artifacts and equipment on the Moon. The fi rst step is to clearly distinguish between U.S. artifacts left on the Moon, such as fl ags and scientifi c equipment, and the territory they occupy. The second is to gain international, not unilateral, recognition for the sites upon which they rest. Aside from debris from crash landings (by Japan, India, China, and the European Space Agency), there are only two nations with “soft-landed” equipment on the lunar surface: the United States and Russia. China has plans to soft-land Chang’e 3 on the Moon in December 2013. All three nations (and any others wishing to participate) have much to gain and little or **nothing** **to** **lose** **from** a **multinational** **agreement** based on mutual respect and mutual protection of each other’s historical sites and equipment. Legal Issues Although ownership of planets, the Moon, and celestial bodies is prohibited, ownership of equipment launched into space remains with the nation or entity that launched the equipment, wherever that equipment is in the solar system. Under the OST, that nation is both responsible and liable for any harmful acts that equipment may create in space. There are no prescribed limits on time or the amount of damage a nation may have to pay. The U.S. government therefore still owns equipment it placed on the Moon. Ownership has the associated right of protecting the equipment, subject to using necessary and proportional means for protection. But, because no nation can claim ownership of the territory on which equipment rests, there is an open issue of how to control the spots on the Moon underneath that equipment, because the site is **integral** **to** the **historical** **signifi** **-** **cance**. In H.R. 2617, establishment of Apollo sites as a unit of the U.S. National Park System could be interpreted as a declaration of territorial sovereignty on the Moon, even though ensuing paragraphs specify the Park’s components as the “artifacts on the surface of the Moon” at those sites. This problem needs international legal clarifi cation, achievable via a formal agreement among those nations that have the technological ability to directly access the Moon ( 5). Section 6(a) raises another legal issue. The bill proposes that the Secretary of the Interior shall administer the park in accordance with laws generally applicable to U.S. National Parks. It also requires the Secretary to act in accordance with applicable international law and treaties. The U.S. National Park System Act states that the Parks are “managed for the benefi t and inspiration of all the people of the United States” ( 6). The OST clearly emphasizes that the exploration and use of space by nations is to benefi t all peoples. The laws and space policies of the United States have always emphasized peaceful uses of space and the benefi ts of space for humankind. It may not be possible to implement and execute provisions of this Bill without raising important and fundamental questions about these contradictions between the language of the treaty and the mandates of our National Park Service. A third legal issue is raised in section (6) (c)(2) that allows private donations and cooperative agreements to “provide visitors centers and administrative facilities within reasonable proximity to the Historical Park.” This **implies** **future** **private** **use** of the Moon **under** **rights** **granted** **by** the **U.S.** government. **Unilateral** **granting** **of** lunar territorial **rights** to private individuals and implicit sovereign protection of that territory **violates** the **OST**. Finally, section 8 of the bill requires the Secretary of the Interior to submit the Apollo 11 lunar landing site to the United Nations Educational, Scientifi c, and Cultural Organization (UNESCO) for designation as a World Heritage Site. This violates Article II of the OST. All current World Heritage Sites are located on sovereign territory of nations. The only exception is a separate treaty that allows UNESCO to designate underwater sites (such as sunken ships) as protected cultural sites ( 7). These designations are very limited, and although the convention has been ratifi ed by 43 nations, the United States, Russia, and China are not among them. Thus, any new treaty of this type specifi cally for outer space would have little chance of being ratifi ed by the major space-faring nations. A Proposal to Protect Lunar Sites Although a new U.N. treaty for space artifacts of signifi cant cultural and historic importance may be reasonable someday, this would start a very long process with unknown outcomes. Such a treaty could be delayed to a point beyond the time when nations and/or companies may be active on the Moon ( 8). Our suggested alternative is to create a bilateral agreement between the United States and Russia, offered as a multilateral agreement to other nations with artifacts on the Moon. This would be more legally expedient, politically sustainable, and would more likely meet and exceed the stated goals of the bill. It would also emphasize the important role of national laws to implement and enforce these international space agreements. **Any** **nation** **with** **assets** on the lunar surface will **endeavor** **to** **protect** those assets. This creates a situation where those nations have a **timely**, **current**, and **common** **interest** incorporating important implications for peaceful uses of outer space; **scientific** **research** and the advancement of **knowledge**; and **cultural** **and** **heritage** **value**, either presently or in the foreseeable future. The United States, Russia, and China all engage in multilateral cooperative space programs. They share many economic and trade dependencies adding to the international importance of promoting cooperation in space and commerce. In spite of today’s charged political environment, an **agreement** of the type we propose may still be possible to negotiate because it **focuses** **on** the **culture** **of** **space**, the use of space to benefit humankind, and the **archaeological** **record** of our civilization. It specifi cally would not touch sensitive issues of real property rights, export controls, human rights, or the weaponization of outer space. **Cooperation** on recognizing and protecting each other’s interests in historical sites and on equipment and artifacts also has no signifi cant security, prestige, or technological impediments. It reinforces the basic principles of the existing space treaties, avoids declarations of sovereignity on the Moon, and encourages multilateral cooperation resulting in a more stable and predictable environment for private activities on the Moon. The best mechanism for implementing a new agreement would be direct negotiations at highest levels of government in the United States, Russia, and China, with priority to include Russian sites in a proposal that protects U.S. sites. It could be included in meetings of heads of state of those nations, either jointly or sequentially among the three nations. Such an agreement could be executed in a relatively short period of time, setting precedents for peaceful and coordinated research, exploration, and exploitation of the Moon ( 9). An international agreement on lunar artifacts among the United States, Russia, and China would be a far superior and long-lasting solution than the unilateral U.S. proclamation in H.R. 2617. Enforcement of the agreement would be through each nation’s national laws, applying to those entities subject to the jurisdiction or control of the agreement members. Each nation’s property would be protected and preserved. Other nations should be free to join the agreement, and particularly encouraged to do so if they have the ability to access the Moon. An important result would be to develop a new level of trust among nations that could then lead to more **comprehensive** **future** cooperative agreements on **space**, **science**, **exploration**, **commerce**, **and** the use of the Moon and **other** **celestial** **bodies**.

#### Heritage Sites are critical for science research around Dust.

OSTP 18 Office of Science and Technology Policy March 2018 “PROTECTING & PRESERVING APOLLO PROGRAM LUNAR LANDING SITES & ARTIFACTS” (The Office of Science and Technology Policy is a department of the United States government, part of the Executive Office of the President, established by United States Congress on May 11, 1976, with a broad mandate to advise the President on the effects of science and technology on domestic and international affairs.)//Elmer

The Moon continues to hold great significance around the world. The successes of the Apollo missions still represent a profound human technological achievement almost 50 years later and continue to symbolize the pride of the only nation to send humans to an extraterrestrial body. The Apollo missions reflect the depth and scope of human imagination and the desire to push the boundaries of humankind’s existence. The Apollo landing sites and the accomplishments of our early space explorers energized our Nation's technological prowess, inspired generations of students, and greatly contributed to the worldwide scientific understanding of the Moon and our Solar System. Additionally, other countries have placed hardware on the Moon which undoubtedly has similar historic, cultural, and scientific value to their country and to humanity. Three Apollo sites remain scientifically active and all the landing sites provide the opportunity to learn about the changes associated with long-term exposure of human-created systems in the harsh lunar environment. These sites offer rich opportunities for biological, physical, and material sciences. Future visits to the Moon’s surface offer opportunities to study the effects of long-term exposure to the lunar environment on materials and articles, including food left behind, paint, nylon, rubber, and metals. Currently, very little data exist that describe what effect temperature extremes, lunar dust, micrometeoroids, solar radiation, etc. have on such man-made material, and no data exist for time frames approaching the five decades that have elapsed since the Apollo missions. While some of the hardware on the Moon was designed to remain operational for extended periods and successfully telemetered scientific data back to the Earth, much of what is there was designed only for use during the Apollo mission and then abandoned with no expectation of further survivability. How these artifacts and their constituent materials have survived and been altered while on the lunar surface is of great interest to engineers and scientists. The Apollo artifacts and the impact sites have the potential to provide unprecedented data if lunar missions to gather and not corrupt the data are developed. These data will be invaluable for helping to design future long-duration systems for operation on the lunar surface. NASA has formally evaluated the possible effects of the lunar environment and identified potential science opportunities. For example, using Apollo 15 as a representative landing site, the crew left 189 individually cataloged items on the lunar surface, including the descent stage of the Lunar Module, the Lunar Roving Vehicle, the Apollo Lunar Surface Experiments Package, and a wide variety of miscellaneous items that were offloaded by the astronauts to save weight prior to departure. The locations of many of these items are well documented, and numerous photographs are available to establish their appearance and condition at the time they were left behind.

#### Moon Dust Research key to Moon Basing.

Smith 19 Belinda Smith 7-18-2019 “Who protects Apollo sites when no-one owns the Moon?” <https://www.abc.net.au/news/science/2019-07-19/apollo-11-moon-landing-heritage-preservation-outer-space-treaty/11055458> (Strategic Communications Advisor at Department of Education and Training at University of Victoria)//Elmer

It's not just about history Alongside heritage value, the bits and pieces left on the Moon have enormous scientific significance. Take moon dust. It's a real problem for moon-bound equipment because it's made of fine, super sticky and highly abrasive grains, which have a habit of clogging instruments and spacesuits. But as Armstrong and Aldrin trotted across the surface, the footprints they left behind gave us valuable information into the properties of moon dust, Flinders University space archaeologist Alice Gorman said. "The ridges on the boots were meant to measure how far they sank into the dust. "Then they used the light contrast between the ridges to measure the reflectance properties of the dust." A boot print in grey dust. This iconic photo of Buzz Aldrin's footprint is also a science experiment. (Supplied: NASA) It's data like this that will help if we want a long-term base on the Moon — we need to know how our gear will stand up to lunar conditions. Apart from the sticky, gritty dust, the lunar surface is also peppered with meteorites and cosmic rays. So, Dr Gorman said, one of the very few reasons to revisit a moon site is to collect some of the equipment left behind and see how it fared. "What has happened to this material in 50 years of sitting on the lunar surface? "This is going to be really interesting scientific information because it will help planning for future missions and get an understanding of long-term conditions." And NASA has already done this. The Apollo 12 mission, which landed on the Moon four months after Apollo 11, collected parts from the 1967 Surveyor probe and brought them back to Earth. An astronaut standing next to a piece of equipment on the lunar surface Along with rocks and soil samples, Apollo 12 astronauts collected pieces of the Surveyor 3 probe for analysis back on Earth. (Supplied: NASA) Another reason to preserve the equipment left on the Moon is to prove we really went there, Professor Capelotti said. "There's a lot of people out there who still don't believe it happened. "The stuff on the Moon is a testament to what we did and when we did it."

#### A lunar base is coming now but preservation of the environment is key.

**Shekhtman 21** [Lonnie Shekhtman, Lonnie is a senior science writer for Nasa. 1-26-2021, "NASA’s Artemis Base Camp on the Moon Will Need Light, Water, Elevation," <https://www.nasa.gov/feature/goddard/2021/nasa-s-artemis-base-camp-on-the-moon-will-need-light-water-elevation/> accessed 2/12/22] Adam

American astronauts in 2024 will take their first steps near the Moon’s South Pole: the land of extreme light, extreme darkness, and frozen water that could fuel NASA’s Artemis lunar base and the agency’s leap into deep space.

Scientists and engineers are helping NASA determine the precise location of the [Artemis Base Camp](https://www.nasa.gov/feature/nasa-outlines-lunar-surface-sustainability-concept) concept. Among the many things NASA must take into account in choosing a specific location are two key features: The site must bask in near continuous sunlight to power the base and moderate extreme temperature swings, and it must offer easy access to areas of complete darkness that hold water ice.

While the South Pole region has many well-illuminated areas, some parts see more or less light than others. Scientists have found that at some higher elevations, such as on crater rims, astronauts would see longer periods of light. But the bottoms of some deep craters are shrouded in near constant darkness, since sunlight at the South Pole strikes at such a low angle it only brushes their rims.

These unique lighting conditions have to do with the Moon’s tilt and with the topography of the South Pole region. Unlike Earth’s 23.5-degree tilt, the Moon is tilted only 1.5 degrees on its axis. As a result, neither of the Moon’s hemispheres tips noticeably toward or away from the Sun throughout the year as it does on Earth — a phenomenon that gives us sunnier and darker seasons here. This also means that the height of the Sun in the sky at the lunar poles doesn’t change much during the day. If a person were standing on a hilltop near the lunar South Pole during daylight hours, at any time of year, they would see the Sun moving across the horizon, skimming the surface like a flashlight laying on a table.

“It’s such a dramatic terrain down there,” said [W. Brent Garry](https://science.gsfc.nasa.gov/sed/bio/william.b.garry), a geologist at NASA’s Goddard Space Flight Center in Greenbelt, Maryland. Garry is working with engineers on a virtual reality tour of the Moon’s South Pole to help immerse astronauts, scientists, and mission planners in the exotic environment of that region as they prepare for a human return to the Moon.

While a base camp site will require lots of light, it is also important for astronauts to be able to take short trips into permanently dark craters. Scientists expect that these shadowed craters are home to reservoirs of frozen water that explorers could use for life support. “One idea is to set up camp in an illuminated zone and traverse into these craters, which are exceptionally cold,” said NASA Goddard planetary scientist [Daniel P. Moriarty](https://science.gsfc.nasa.gov/sed/bio/daniel.p.moriarty), who’s involved with NASA’s South Pole site analysis and planning team. Temperatures in some of the coldest craters can dip to about -391 degrees Fahrenheit (-235 degrees Celsius).

Initial plans include landing a spacecraft on a relatively flat part of a well-lit crater rim or a ridge. “You want to land in the flattest area possible, since you don’t want the landing vehicle to tip over,” Moriarty said.

The landing area, ideally, should be separated from other base camp features — such as the habitat or solar panels — by at least half a mile, or 1 kilometer. It also ought to be situated at a different elevation to prevent descending spacecraft from spraying high-speed debris at equipment or areas of scientific interest. Some scientists have estimated that as a spacecraft thrusts its engines for a soft landing, it could potentially spray nearly a million pounds, or hundreds of thousands of kilograms, of surface particles, water, and other gases across the surface.

“You want to take advantage of the landforms, such as hills, that can act as barriers to minimize the impact of contamination,” says [Ruthan Lewis](https://www.nasa.gov/nesc/academy/ruthan-lewis-bio" \t "_blank), a biomechanical and industrial engineer, architect, and a leader on NASA’s South Pole site analysis and planning team. “So, we’re looking at distances, elevations, and slopes in our planning.”

At the Moon, it’s critical to keep the area around the landing site and base camp as pristine as possible for scientists. For instance, among the many interesting features of the South Pole region is its location right between the Earth-facing side of the Moon, or the near side, and the side we never see from Earth, known as the far side.

These two hemispheres are geologically very different, with the far side more heavily cratered and its crust thicker than on the near side. Scientists don’t know why the two sides formed this way.

The Artemis Base Camp has to be on the Earth-facing side to make it easier for engineers to use radio waves to communicate with astronauts working on the Moon. But scientists expect that over billions of years of meteorite impacts to the Moon’s surface, rocks, and dust from each hemisphere were kicked up and strewn about the other, so it’s possible that astronauts could collect samples of the far side from their base camp on the near side.

#### Scenario 1 – Aquaculture:

#### Lunar Basing would require aquaculture that provides mutual benefits that spill-down terrestrially – results in sustainable aquaculture and solves food scarcity

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Space Aquaculture: A Relevant Source of Complementary Nutrition Resupplying a base in space from Earth on a weekly basis is neither economically nor technologically feasible (a trip to the Moon takes 4–7 days, and to Mars 5–8 months). A short-term solution is to provide processed and prepackaged space food. However, lyophilized conservation is unstable, especially concerning essential nutrients such as potassium, calcium, vitamin D, and vitamin K, which is involved in muscle and bone maintenance. The micronutrients most sensitive to storage degradation are vitamins A, C, B1, and B6 after one year at ambient temperature (Cooper et al., 2017). A possible nutrition strategy for space bases could be to couple local fresh production with supplies brought by cargo spaceships. Providing fresh, nutritious and safe food is imperative for the success of a manned base on Moon or Mars. Recent studies have shown that food energy needs during a spaceflight are similar to those required on Earth. If energy intake is reduced, the human body is subjected to physiological stress causing cardiovascular deconditioning, bone demineralization, muscle atrophy and immune system deficiency. Moreover, microgravity exposure reduces the nitrogen balance in an astronaut’s body. This results in a 30% reduction in protein synthesis (Stein, 2001). A study of previous manned missions in low orbit monitored the crew’s physical performance consuming food commonly used in space missions and showed that an increase in carbohydrates (from plants) and a decrease in animal protein and fat can disturb the diet balance (Gretebeck et al., 1994). Ideally, a fresh animal-based food source should be included in the diet of space residents. Seafood is one of the healthier animal products for human nutrition. Its nutritional merits and protective benefits have been abundantly described over the last century. Like wild fish, aquaculture fish sequester digestible proteins and essential amino acids, lipids, including essential polyunsaturated fatty acids (PUFAs), essential vitamins and minerals in their muscles. Vitamins are precursors of molecules that are essential coenzymes for enzyme catalysis. When the synthesis of coenzymes is not included in an organism’s genetic heritage (this is the case for Homo sapiens), their natural synthesis must be achieved by the ingestion of living cells. These cells are provided by a diet of plants or animals. In addition to micronutrients, farmed marine, brackish and freshwater fish can sequester ALA (PUFA precursor), EPA or DHA from their diet (Tocher, 2015). Several aquaculture fish have the physiological capability to produce EPA and DHA (ALA chain elongation) and store these essential compounds (Morais et al., 2015; Gregory et al., 2016). The micronutrients commonly found in fish and their health benefits are presented in Table 1 (Tacon et al., 2020). At the beginning of the 1980s, the first study on the possibility of space aquaculture emphasized the shared points between recirculating aquaculture systems (RAS) and BLSS (Hanson, 1983). Yet although aquaculture seems to offer a relevant solution for manned long-term missions (Bluem and Paris, 2003), almost four decades later, no significant innovative solutions have been proposed for space exploration. This may be due to the international strategy of developing low orbit science over the last 30 years with the ISS program, to the detriment of more complex and ambitious projects such as trips to the Moon or Mars involving long-term stays. Why Raise Aquatic Organisms in Space? Hydrogen and oxygen are abundant in the Universe, and water molecules are everywhere in the solar system. Sub-glacial liquid water has been detected on many rocky planets such as Mars, Mercury, and Venus (Liu, 2019; McCubbin and Barnes, 2019). There is evidence of the presence of an internal ocean on icy moons such as Enceladus (Cadek et al., 2016) and Europa (Kalousova et al., 2016). Recent research has indicated the presence of water molecules on rocky exoplanets from other solar systems in our galaxy (Olson et al., 2020). Water is the main in situ resource required for a planetary mission, both for long-term human settlement or astrobiology considerations; however, most observations have revealed that this water has high mineral content or is close to brine due to geological mineralization (Orosei et al., 2018). It would need to be purified to use as a source for water of drinking quality, yet it could be primarily used for rearing marine organisms such as algae, invertebrates, or fish. Today, producing protein from farmed animals (poultry, cattle, or sheep) in low gravity does not seem feasible. A large surface area is needed for livestock rearing, which would directly compete with human space, and costly synthetized air reconditioned from precious in situ resources such as lunar or planetary water or gas produced by BLSS biotechnology would be reserved for the human residents’ artificial atmosphere. Due to their poikilothermic physiology, fish require five to twenty times less energy than mammals, and around three times less oxygen, as well as generate less carbon dioxide emissions, which is an important consideration for BLSS gas exchange management. Another issue is waste management. With terrestrial animals such as pigs, chickens, goats, or cows, feces collection is not easy to solve. However, in aquatic vertebrate production, all dissolved compounds and particulate matter are sequestered in the water and can be easily treated and removed from the system or converted by another organism. Lastly, compared to terrestrial farmed animals, aquaculture is commonly viewed as playing a major role in improving global food security on Earth because the feed conversion ratio (FCR: the feed biomass necessary to provide to a farmed organism to obtain a weight increase of 1 kg) for fish is drastically lower than for land vertebrates. The FCR for different aquaculture organisms compared to that of the main farmed land animals is shown in Figure 1. Protein and calorie retention from aquaculture production is comparable to livestock production (Fry et al., 2018). All aquatic vertebrates exhibit better feed efficiency, which implies less feed to produce in a BLSS and to manage on the Moon or Mars. Gas management in lunar or Martian bases will probably be the main challenge for engineers in the next decade. On Earth, the atmosphere sequesters a stock of oxygen, and its continuous production is provided by oceanic and terrestrial photosynthetic organisms. Before the Industrial Revolution, carbon dioxide production was balanced with oxygen consumption. Today, even with the rise in CO2 emissions, oxygen is not a limited source. In contrast, in a closed system in an extreme environment such as the Moon or Mars, oxygen is not available in its basic form and must be produced. Hence, it is a precious molecule and it is of particular interest to include low oxygen consumers–and consequently, low carbon dioxide producers–in a BLSS. Compared to animals that breathe air, fish, and more generally aquatic organisms, have the lowest oxygen requirement and are the lowest producers of carbon dioxide (Figure 2). In fish, carbon dioxide production from respiration is dissolved, concentrated and stored in the water column. Fish have been shown to maintain their oxygen consumption under conditions of elevated CO2 partial pressure (Ishimatsu et al., 2008). The dissolved CO2 from RAS effluent could be used directly by an aquatic photosynthetic organism such as algae. Collecting CO2 emitted from fish and dissolved in the water column and directing it to a secondary biological system without an additive process would be a huge advantage for BLSS gas management. In contrast to farmed poultry and mammals, aquatic organisms would also be protected from cosmic rays by the water environment, which is an intrinsic radiation shield. The first life forms on Earth developed in a brackish ocean with a salinity of around 10 mg/L (Quinton, 1912). Complex life emerged from the Earth’s oceans when the atmospheric layer had not yet been totally formed by the respiration of microorganisms (stromatolites, bacteria and microalgae) and volcanic activity. The thin atmosphere exposed the Earth’s surface to intense cosmic radiation. The hypothesis that water played a role as a radiation shield in the appearance of aquatic life is strong and plausible. In connection with the development of space aquaculture, further experiments would be needed to determine the integrity or splitting of a heavy charged particle from cosmic radiation entering the water of an aquaculture tank. Transporting any type of animal in a space mission would subject them for several minutes to hypergravity between 4 and 8 g (unit of acceleration due to gravity) depending on the space engine. But hypergravity conditions are not unknown for oceanic fish such as the bluefin tuna (Thunnus thynnus). In one stress experiment, the force required for maximal acceleration was measured in this species. The associated hypergravity applied to the tuna was around 3 g for a few seconds (Dubois et al., 1976). No experiments have been conducted on aquaculture fish, but the natural acceleration caused by an escape behavior has been recorded as between 1 and 3 g. Another argument in favor of finfish as candidates for space aquaculture is that as opposed to other reared vertebrates and humans, in the water column they can move vertically as well as horizontally. Fish use a ballast system, the swim bladder, and otolith sensitivity to move in a volume of water, experiencing gravity but also buoyancy. In the ocean, fish are already in microgravity conditions due to water density and Archimedes’ principle. Thus, altered gravity should not interfere with swimming behavior during the lifecycle of a fish. Experiments have revealed that a fish in microgravity during a space mission orients its swimming direction and body position according to the position of the light in the module without losing the ability to feed or affecting social behavior. Fish movement can also be correlated with spaceship rotation (Ibsch et al., 2000; Anken et al., 2002). Indeed, astronauts train underwater as this is the best way to imitate the weightless conditions found in space. The suits they wear in the training pool are designed to provide neutral buoyancy (like a fish’s swim bladder) to simulate the microgravity experienced during spaceflight (Otto F.Trout, 1969). Spaceflight analog missions are conducted underwater in NASA’s Extreme Environment Mission Operations (NEEMO), involving multi-hour activities at a depth of 19 m (Koutnik et al., 2021). While the hypothesis that the variation in space gravity will not drastically disturb the fish from a physical, behavioral or welfare point of view is plausible, this remains to be tested in experiments on aquaculture fish species. Ornamental Fish as a Model for Understanding Human Physiology in Space The zebrafish Danio, the medaka Oryzias, and the swordtail fish Xiphophorus have been frequently boarded on space missions as models for understanding human gravitational sensations, due to the homology with human morphological and physiological systems. These species have proved the most suited vertebrate animals for basic gravity research. The gravity-sensing system in vertebrates from fish to humans has the same basic structure. Although aquarium fish are not aquaculture fish, space missions over the last five decades have provided useful results on fish physiology, behavior and well-being in microgravity (Lychakov, 2016). The earliest spaceflight with fish occurred on July 28, 1973. Two fingerlings and fifty embryonated eggs of the mummichog (Fundulus heteroclitus) were launched by a Saturn 1B rocket. The Apollo service module joined Skylab 3 and the fish were positioned in a plastic bag filled with seawater. This American space mission preferred the mummichog, a small saltmarsh killifish, to goldfish for this experiment. This species was not well known or described at that time, but it became the first “fishonaut”. For three days, swimming in loops and circles was observed for the two fingerlings, but they gradually returned to normal swimming. The fish acclimation period was comparable to that for a human crew during a first spaceflight. This observation suggested that the vestibular function (the otolith for fish–the inner ear for humans) probably plays the same sensory role in microgravity. The Fundulus heteroclitus eggs carried aboard the Skylab station in low orbit hatched successfully during the mission with a very good hatching rate (96%). The hatched fry displayed normal swimming behavior in contrast to the first hours in microgravity for the fingerlings (Baumgarten, 1975). Fish embryos in microgravity develop a physiological strategy to compensate for the unusual environment, and the larvae formed were already adapted to microgravity, as evidenced by the lack of looping behavior. In 1975, during nine days of the manned Apollo-Soyuz MA-161 mission, a group of 21-day-old juvenile mummichogs were exposed to real microgravity, and similar irregular swimming was observed. Fish eggs were also boarded (n = 100/samples at 32 hpf [hours post-fertilization], 66 hpf, and 128 hpf stages; pre-liftoff fertilization times) and were subjected to post-flight hatching rate evaluation back on Earth. The juveniles were evaluated using light orientation tests, and no significant differences were observed in behavior, suggesting an adaption capability to the space environment. The embryo hatching rate was 75%, and hatching date monitoring showed that the three earliest stages of egg batches carried on Apollo-Soyuz hatched at 15 days (normal hatching rate is 21 days), much sooner than the latest stage batch and earlier than the control batches at 1 g. Apparently, the development of young eggs was faster under microgravity, but the embryos exhibited no abnormalities resulting from development in a zero-gravity environment. The eyes, heart, nerves, and bones were found to be the same in the flight group as in the control group. There was no evidence of calcium deficiency, except in the shorter hatching-time group (Hoffman et al., 1977). In July 1994, the 17th Columbia space shuttle mission STS-65 boarded Japanese medaka (Oryzia latipes) for 15 days of spaceflight in the second International Microgravity Laboratory (IML-2). These ornamental fish laid eggs, and normal hatching was observed in space, with the results showing that medaka fertilization and embryonic development was not significantly impaired by altered gravity (Ijiri, 1998). Probably the most impressive aquatic closed-loop experiment in low orbit and a successful demonstration of an aquatic trophic chain in space, in the 1990s, a German team from Ruhr University Bochum and the German Aerospace Centre (DLR) developed the Closed Equilibrated Biological Aquatic System (CEBAS) with fresh water, containing small aquarium fish (Xiphophorus hellerii), water snails (Biomphalaria glabata), aquatic plants (Ceratophyllum dermersum), and aquatic microorganisms. The ground-based demonstration showed that a filter system was able to keep a closed artificial aquatic ecosystem stable for several months and to eliminate waste products deriving from degraded dead fish without a decrease in oxygen concentration to less than 3.5 mg/I at 25°C (Blum et al., 1994; Blum et al., 1995). Then in January 1998, during the Endeavour space shuttle mission STS-89 to the MIR station, aquarium swordtail fish (Xiphophorus helleri) were exposed to 9 days of microgravity, with 200 juveniles and four pregnant adult fish carried in a mini CEBAS module (10 L) (Blum et al., 1994). The aim of this aquatic mini-module (Figure 3) was to record the behavior of an artificial ecological closed loop in low orbit and verify the hypothesis that aquatic life is not affected by exposure to space conditions using a complementary organism. The female fish were retrieved in good physiological condition, adult and juvenile fish had a survival rate of about 33%, and almost 97% of the snails had survived and produced more than 250 neonates in microgravity (Bluem et al., 2000). During the spaceflight, the vertebrates were video-recorded for behavioral analysis and no aberrant looping or spinning behavior was observed. Immediately after landing back on Earth, the adult fish swam vertically, head upward, to the top of their habitat, strongly beating the caudal and pectoral fins. This was due to empty swim bladders not used during the spaceflight and reuse acclimation on Earth (Anken et al., 2000; Bluem et al., 2000; Rahmann and Anken, 2002). In April 1998, another population of swordtail fish and four adult wild marine fish oyster toadfish (Opsanus tau) flew with the space shuttle STS-90 mission, hosted in the Neurolab facility. After 16 days in real microgravity, fish brain synaptic contacts were compared to a control population at 1 g on Earth. Spaceflight yielded an increase in synaptic contacts within the vestibular nucleus indicating a compensation processes for neonates swordtail fish (Ibsch et al., 2000). Results revealed a gravity compensation process and the role of the fish lateral line associated to the fish brain for appropriate swimming behavior (Anken et al., 2002). The Vestibular Function Experiment Unit (VFEU) aboard STS-95’s SpaceHab again hosted two oyster toadfish as experimental subjects. The fish were electronically monitored to determine the effect of gravitational changes on the otolith system. The freely moving fish provided physiological signals of the otolith nerves. Measurements of afferent and efferent responses were made before, during, and post-flight (Boyle et al., 2001). In January 2003, four medaka eggs laid on Earth in an artificially controlled environment were launched by the Columbia space shuttle during the STS-107 mission. For the control, four eggs in the same condition remained on the ground. No difference was observed in the time of development. In the ground experiment, the embryos were observed to rotate in the egg membrane, whereas in flight they did not rotate. One egg hatched 8 days after the mission launch in the flight unit, while four eggs hatched in the ground unit. In the flight unit, the fry was observed with its back usually to the camera and little swimming movement suggest. The results shown no appreciable difference in the time course of development between space- and ground-based embryos. (Niihori et al., 2004). The hatched medaka larva, embryos and the crew from the space mission tragically never returned to Earth alive due to the accident during the space shuttle’s reentry in the atmosphere. In 2007, dry eggs of the ornamental killifish the redtail notho (Nothobranchius guentheri) were placed into cotton-cloth bags, then into plastic Petri dishes, and fastened on the outer side of the ISS. The aim of the Biorisk-MSN mission was to expose dry incubated eggs to low orbit radiation. Unfortunately, no data is available concerning the resistance of the fish eggs as the equipment had no temperature sensor and the plastic dishes reached 95°C, deforming the plates, and the eggs died due to the high temperature and vacuum contact (Baranov et al., 2009). To study the fish response at early stage to microgravity, two missions using medaka fish were performed on ISS, in 2012 and 2014. Each time a Soyuz rocket sent 24 juveniles medaka (6 weeks after hatching, 16 mm) with the objective of rearing this population in the Aquatic Habitat (AQH) on the Kibo section of the ISS. Medaka fish in space and control fish from the same family on Earth were filmed. The movies showed that the fish became adapted to life under microgravity although despite an unusual swimming behavior. In addition, a mating behavior was observed under microgravity at day 33 and was not different from that on the Earth, indicating microgravity environment doesn’t disturb fish reproduction. The aquarium fish used for this experiment have fluorescent osteoclast cells, which makes them easier to observe. An osteoclast is a type of bone cell that breaks down bone tissue and responsible for bone loss. After 47 days in space, the fish tended to stay still in the tank. After 56 days, the mission fish group had normal growth compared to a terrestrial control. For fish in microgravity impairment of some physiological functions was accompanied by the activity of osteoclasts and a slight decrease in mineral density and vertebral bones. (Chatani et al., 2015; Murata et al., 2015; Chatani et al., 2016). Historical space missions involving ornamental fish are listed in Table 2. Missions With Aquaculture Fish in Low Orbits Very few missions involving aquaculture fish have been carried out to date (Table 3). In one of these, the common carp (Cyprinus carpio)—considered a very important aquaculture species in many countries–was chosen as a model for a sensor motor experiment by Japanese university teams and the Japan Aerospace Exploration Agency (JAXA). Two colored carp (16 months old, 26 cm and 263–270 g) were carried to the American SpaceLab in 1992. One of the two carp was given a labyrinthectomy (the otolith was removed). For both fish, swimming behavior and dorsal light response was studied and compared. As observed during the first space missions with small fish, the normal carp was unstable (associated with a kind of space motion-sickness) for the first three days, then finally recovered its Earth-based swimming behavior. The fish whose otolith was removed two months before showed a normal dorsal light response 22 h after launch, and disruption for the next two days as with the normal carp. Unfortunately, the recovery process for the fish with the removed otolith could not be evaluated due to a technical issue, but these observations provided evidence of a sensory-motor disorder during the early phase of adaption to microgravity in aquaculture fish (Mori et al., 1996). The change in body weight was monitored from two days before launch to four days after landing. Both fish recorded a weight loss around 12% in low orbit after 14 days of fasting. No conclusion can be made as a fasting replicate on the ground was not available (Mori et al., 1994). During space shuttle missions STS-55 (1993) and STS-84 (1997), tilapia Oreochromis mossambicus larvae that had not yet developed the roll-induced static vestibuloocular reflex were exposed to microgravity for 9–10 days. Young larvae (11–14 days after hatching) already exhibited the vestibuloocular reflex on the 1993 mission. Back on Earth, a vestibuloocular reflex test (fish were turned around their longitudinal axis at an angle of 15, 30, and 45°) showed that eye movement and reflex were not affected by exposure to microgravity during the two space missions (Sebastian et al., 2001). The OMEGAHAB (Aquatic Habitat) is a closed artificial ecosystem that was sent into orbit for 13 days on board the Russian satellite FOTON-M3 in 2007. The goal of the mission led by the German Space Agency was to investigate the possibility of designing a trophic chain in real microgravity using the photosynthetic flagellate Euglena gracilis as an oxygen producer and larvae of tilapia Oreochromis mossambicus as a consumer. This freshwater and brackish species is a popular aquaculture fish, with worldwide production of around 15,000 tons per year. In the 2007 experiment, 26 small larvae (approx. 12 mm in length) in the flagellate aquarium were studied in low orbit to increase knowledge about the development of the vestibular organs and enzymatic activity. The best fish survival rate (42%) ever achieved in a German experiment was recorded. Conditions of real microgravity during spaceflight induced a larger than normal otolith compared to a control maintained at 1 g. This could result in a difference in the ability to sense gravity (Anken et al., 2016). In a same ground unit, the photosynthetic producers supplied sufficient amounts of oxygen to a fish compartment with 35 larval cichlids (Hader et al., 2006). Historical space missions involving aquaculture fish are listed in Table 3. Feeding Fish in Space: Integrated Multi-Trophic Aquaculture If fish were farmed on a space base, sending aquaculture feed from Earth to Moon or Mars would make no sense from an economic or lifecycle analysis point of view. Aquatic systems contain a large diversity of species with different roles in nutrient cycles and biomass conversion that contribute to ecosystem balance. Photosynthetic organisms (algae, phytoplankton), invertebrates (crustaceans, mollusks, zooplankton), vertebrates (fish, amphibians), and microorganisms interact in a complex trophic web. By associating different complementary species such as fish, filter feeders, detritivores and primary producers, integrated multi-trophic aquaculture (IMTA) provides an innovative possibility for BLSS on the Moon or Mars. The nutritional profile of fish is closely linked to their diet quality. In aquaculture, this can be easily adjusted by ensuring a fish feed formulation that includes organisms that synthesize or sequester proteins, lipids of interest (e.g., EPA or DHA), vitamins and minerals. These aquatic organisms can be cultivated separately in a chain (from algae to invertebrates to fish) exclusively with fish waste as a fertilizer or using other available waste from human activities, such as exhaled carbon dioxide, space agriculture byproducts, or residents food waste. In the framework of sustainable aquaculture on Earth, researchers are studying trophic webs using closed or semi-closed aquatic systems that reuse fish nutrients dissolved in the water column or fish fecal matter as a fertilizer or food source for another aquatic organism. In an IMTA system, microalgae or macroalgae cultivation is easy using fish tank effluents, as the N/P ratio fits the requirements of algae: the increasing algae biomass assimilates nitrogen and phosphorus forms (Pagand et al., 2000). To return treated water back to the fish tank, it can be cleaned so it is safe for fish growth and welfare (Mladineo et al., 2010). Moreover, fish farm effluent is a suitable media for cultivating Nannochloropsis gaditana, a marine algae with a high PUFA content (Dourou et al., 2018). Several studies have reported the possibility of feeding aquaculture fish with microalgae (mostly marine) included in the fish feed formulation. Several microalgae strains have been tested successfully (they do not alter growth kinetics or organoleptic quality) with fish feed made up of 20–40% of microalgae: Crypthecodinium sp., Phaeodactylum sp. (Atalah et al., 2007) and Schizochytrium sp. (Ganuza et al., 2008; Stuart et al., 2021) have been tested for the seabream and amberjack diet; Tetraselmis sp. (Tulli et al., 2012), and Isochrysis sp. (Tibaldi et al., 2015) for European seabass; Nanofrustulum sp. for salmon, common carp and schrimps (Kiron et al., 2012); and Tetraselmis sp. and Isochrysis sp. for cod (Walker and Berlinsky, 2011). The modern feed form for aquaculture fish is dried pellets with less than 10% moisture. However, a study has shown that feeding fish using a moist formulation, such as algae or aquatic worms, with a water content around that of the natural prey profile in oceans, did not affect fish growth parameters and in fact increased resistance and immune protection (Przybyla et al., 2014). Thus, photosynthetic or invertebrate aquatic organisms produced in a Moon or Mars greenhouse could be fed directly to aquaculture fish with no transformation process. Researchers are exploring these alternatives to preserve wild fish stocks currently used for aquaculture fish feed (e.g., processed into fish meal and fish oil). Other algae sources with higher integration rates in feed formulations are the focus of future studies, while research is also investigating new types of aquatic prey compatible with fish feed, such as jellyfish (Marques et al., 2016). The algae cultivated in an IMTA system, as well as fish effluent, can also be a feed source for invertebrates, mollusks (Li et al., 2019), and sea cucumbers (Chary et al., 2020). A team from NASA is studying the possibility of using invertebrate production systems to purify water while growing protein-rich species as food/feed sources. Aquatic species such as copepods or mussels should grow rapidly, offer good protein content and have low mass for launch requirements (Brown et al., 2021). In the ocean, copepods and mussels are the favored natural prey of fish (especially seabream) and can be used as live feed for aquaculture fish. This production could also serve as food for the human crew. Thus, aquatic invertebrates and microalgae could play a key role in a trophic chain on a space base. In a recirculating aquaculture system, particulate matter is composed mainly of feces, mucus and bacterial clusters. This waste is easy to separate and remove from the RAS. Some copepods can use this media as feed, but another invertebrate is being studied for its ability to reduce this particulate matter and convert it into valuable biomass: the aquatic worm (Galasso et al., 2020). Polychaeta are detritivores and can be a feed source of interest for fish. Aquatic worms cultivated in an RAS can convert fecal matter into useful fatty acids for fish feed (Kicklighter et al., 2003; Bischoff et al., 2009; Palmer et al., 2014). Other synergies might also be possible: for example, Caenorhabditis elegans is a small terrestrial nematode already studied in space as a model for ageing in microgravity, as 35% of C. elegans genes have human homologs (Honda et al., 2014). This nematode could thus be both cultivated and observed in space in a BLSS. In wild environments on Earth, a fish’s diet is composed of its own congener, algae or invertebrates. Ground-based experiments have evaluated Nile tilapia as a bioregenerative sub-process for reducing solid waste potentially encountered in a space aquaculture system (Gonzales, 2009). The Tilapia feed formulation consisted of vegetable, bacterial, or food waste. Sulfur, nitrogen, protein, carbon and lysine content of waste residues were assimilated, sequestered and recycled in Tilapia muscle. Although Tilapia’s specific growth rate from population fed with different fibrous waste were widely inferior (1.4—89.8 mg/day−1) compared to the control population (281.6 mg/day−1), the Tilapia’s survival rate was not different. These results suggest additional research to improve feed formulation composed with fibrous residues (Gonzales and Brown, 2007). When considering formulating aquaculture fish feed on a space base using exclusively aquatic organisms cultivated in an IMTA system, it is essential to determine the digestive efficiency of the fish feed. A recent study highlighted the extreme flexibility of European seabass to feed formulations without fish meal and fish oil. In the experiment, fish were given several formulations containing 85% plant sources and 15% alternative sources (yeast, insects, and processed animal protein or Arthrospira platensis). Zootechnical results showed that three formulations resulted in a growth equal to fish fed with a traditional commercial formulation including a wild fish source. The bacterial community in the fish digestive tract adapted to the new formulation composed of alternative protein and lipid sources, and bacterial diversity was not altered (Perez-Pascual et al., 2020). This plasticity is probably common to other fish species, allowing a promising avenue to test new innovative formulations for aquaculture fish using exclusively BLSS raw matter sources such as cyanobacteria, plants, algae, and invertebrates. Applicability and Limitations of a Space Aquaculture System Like the systems for other types of food sources being studied for a future BLSS, such as those to produce microalgae and higher plants (Tikhomirov et al., 2007), the design of a space aquaculture system (SAS) is subject to various parameters, including the location in the Solar System. The size of the SAS would depend on the number of residents to feed, the other food sources necessary based on nutritionist’s recommendations, the space available on the lunar base, water availability and quality, the energy available for this activity, and the duration the BLSS will need to operate. One scenario might be to provide around 250 g of fish per person per week. The volume of the tank for rearing the fish should also be correlated to the fish growth rate and the frequency at which the fish are harvested. The diversity of fish species allows possibilities to be imagined such as using the area under the floor of the lunar base for flat fish, for example, or a tank that is not connected to the crew’s living area. On the Moon as on Earth, an aquaculture system requires water circulation. While the energy needed to pump water in an SAS with lunar gravity (one-sixth of Earth’s gravity) is yet to be defined, maintaining a set water temperature will have an energy cost. Within a window of tolerance depending on the species, fish growth directly depends on the water temperature (Handeland et al., 2008). In a context of 14 days of Sun exposure and 14 days of darkness, the latter period will require warming the water to maintain the growth rate. Thus the thermal profile of the selected species will be one of the parameters to consider. This aspect will have a direct impact on the total energy required for an acceptable growth yield in the SAS. Although fish have a low oxygen uptake compared to other vertebrates (Figure 2), a regular supply is required. Oxygen dissolution in the water from hydroxyl extraction and oxygen from the regolith and/or from photosynthesis in plants cultivated in the BLSS must be synchronized with the biological demands of the fish. This requires the capacity to regularly collect, store and dissolve oxygen in the water column. The oxygen data from the CEBAS experiment on the STS-89 and STS-90 missions was analyzed to model this concept. Results based on the experimental MINI-MODULE (8.6 L) showed different periods of oxygen accumulation and depletion in the aquatic habitat in plants (oxygen producer) and snails (oxygen consumer). Simulations from ground-based models predict the oxygen concentration and can be adapted for other species (Drayer and Howard, 2014). A trend has to be defined between the volume of oxygen instantly available or stored and the demand of aquatic consumers. This highlights the importance of an oxygen buffer tank linked to a feedback control mechanism (possibly remotely controlled from Earth) in case of a lack of oxygen. Another aspect to monitor is bacterial development inside the system. An axenic environment cannot be considered as bacteria play an essential role in all stages of a balanced ecosystem. Yet bacteria activity affects the nutrient budget and oxygen measurement and availability (Konig et al., 2001). All these parameters will drive the size of the SAS and the fish biomass allowed in an extreme environment such as the Moon. Another issue to consider is aquatic biomass extraction in the space environment. Harvesting cells such as microalgae is a current challenge, today handled using vacuum and flocculation (Barrut et al., 2012). The development of harvesting tools is required for different aquatic organisms in a limited and constrained space. Regardless of the organism, extraction is necessary when the biomass has reached its optimum growth to avoid uncontrolled water degradation and increased oxygen consumption by microorganisms that would endanger fish production. The time needed for fish management on a lunar base also depends on the size of the SAS. Current technology developed for RAS drastically reduces the time necessary to maintain the system. Most of the tasks can be automated, such as starting and cleaning the biofilter, monitoring water parameters (Konig et al., 2001), and regulating the water. Fish feeding is a time-consuming task, but this can also be automated. Fish are able to adapt to self-feeding devices (Coves et al., 1998; Di-Poi et al., 2008), which contribute to the social interaction of the population (Chen et al., 2002). As in plant production systems (Bamsey et al., 2009), several automated SAS actions could be carried out remotely from a control room on Earth. A daily routine (visual checking of the system and fish behavior and non-automated actions) could be considered to involve around 1 h every 12 h for a closed loop system composed of 16 tanks (1 m3) and 8 kg/m3 of fish biomass (based on personal experience). The energy available to power the SAS will also determine its design. A ground-based greenhouse simulation for food production with lunar constraints is necessary to study and understand gas flow management, organism interactions, and all related parameters necessary to maintain a stable and balanced ecosystem. Studying the Feasibility of Sending Aquaculture Fish Embryos to the Moon: The Lunar Hatch Program In research underway since 2019, the Lunar Hatch program is investigating the feasibility of shipping embryonated aquaculture fish eggs to space for programmed hatching in a lunar BLSS. The hatched larvae would then be fed with local resources and reared until they reached an appropriate size for human consumption. The aim of the study is proof of concept based on experimental data collected first in ground-based trials, followed by test missions in low orbit, and concluding with a real flight to space, perhaps leading to the hatching of the first vertebrate on the Moon. The program focuses on the viability of European seabass (Dicentrarchus labrax) for such a project, by analyzing the potential effects on embryos of a Moon journey and the associated environmental changes. Water found on celestial bodies in the Solar System have a saline or hypersaline profile. The choice of the European seabass in the Lunar Hatch program was based on the fact it is a marine organism with an appreciated taste, and its physiology and behavior have been abundantly described. A secondary water source for fish aquaculture could also be considered such as recycled water from a greenhouse or non-potable water from technical process or human activities. The diversity of aquaculture fish species allows the appliacation of many potential “fishonauts”, depending on the primary or secondary water resource available in situ (fresh or salt water). Other aquaculture species could equally be considered for rearing in space, such as trout, flat fish or shrimp. As mentioned, in the 1970s, spaceflight tests were carried out at the egg stage with ornamental fish (Table 2). The choice of eggs as the biological stage for space travel is relevant for several reasons. A low volume of water is required for egg incubation, so the initial launch biological payload could be less than 1 kg for around 900 future larvae. In aquaculture nurseries, European seabass egg density in the water column is around one egg per milliliter. Unlike the larval or adult stages, the embryogenesis phase is suitable for a spaceflight because embryo development does not require human intervention for several days (the duration of embryogenesis depends on the species). Although embryogenesis involves intense metabolic activity for the development of the future larva, the low biomass and the chorion limit catabolite emission as well as the self-pollution of water during the journey. This would allow either long manned spaceflights with no need for maintenance from the crew, or simply the transport of fish eggs using an automated cargo ship. Compared to normal conditions in land-based aquaculture production, during a spaceflight fish embryos would be initially subjected to atypical acoustic and mechanical vibrations caused by launcher motors and acceleration in the atmosphere. The effects of this are under study in the framework of the Lunar Hatch program (supported by the French National Institute for Ocean Science, Ifremer) using a standard qualification test commonly employed in the space industry. In a recent experiment, a vibration exciter mimicked the conditions of a SOYUZ-2/FREGAT launch on a population of fish embryos (Figure 4). In this test, two triplicates (n = 300) of embryos of aquaculture species (European seabass and meagre in two separate experiments) were submitted to the acoustic and mechanical environment of a launch for 10 min at one-third and two-thirds of their development. The hatching rate was then compared to a control triplicate (n = 300). No significant differences were observed on the hatching rate for either species whatever the stage of development when the embryos were exposed to the conditions (Figure 5). These encouraging results indicate the egg robustness of two major aquaculture species. A credible hypothesis to explain these results is that the success of the global aquaculture industry is based on the selection of aquatic species for robustness criteria to actions such as unusual and stressful handling–especially at an early lifecycle stage–such as sorting, sampling, transfer from aquarium to tank, or long transport by road or air. The aquaculture sector has selected the most biologically flexible strains with the most interesting nutritional profile for economic reasons. The resulting robustness could benefit space programs–it would not be surprising if other aquaculture species also successfully pass this qualifying test. Beyond intense vibrations, understanding the influence of hypergravity and microgravity on embryonic development is essential to evaluate the feasibility of space aquaculture. Previous studies on ornamental aquarium fish can provide some information on fish behavior and physiology in space that may be useful. Hypergravity is experienced during rocket take-off, an acceleration phase that lasts about 10 min at 4–8 g, depending on the launcher motors. This situation was tested on swordtail fish and medaka otoliths (Anken et al., 1998; Ijiri et al., 2003; Brungs et al., 2011; Anken et al., 2016) and larvae bone development (Aceto et al., 2015; Chatani et al., 2015), but its effects on early ontogeny (hatching capability) are as yet poorly described. A recent research showed that six month exposition at 5 g can induce vertebral curvatures and asysmetric otoliths (Chatani et al., 2019). However, the duration of exposure to hypergravity during a launch to the Moon or Mars will be about 10 min, the time to extract the embryos from the Earth’s attraction. Ongoing experiments are exploring the ability of aquaculture finfish embryos to develop in these conditions. It is credible to posit that hypergravity applied to a water reservoir may be less felt by a submerged embryo. In contrast to poultry eggs stored in air, the water density surrounding fish eggs may reduce the acceleration force on the chorion. Following the initial conditions of rocket vibrations and acceleration, a situation of microgravity appears beyond an altitude of 110 km. During the entire evolution of life on Earth, the development of all organisms took place under constant gravity conditions in different media (air/water). It should be noted that in the ocean, fish embryos are already in a kind of microgravity compared to terrestrial organisms due to Archimedes’ principle and other physical phenomena. This is why, to simulate partial microgravity, astronaut training exercises are carried out in a swimming pool. A study has found that embryos of Xenopus (an aquatic frog) are able to adjust to microgravity environments until hatching through an adaptation mechanism and strategy (Black et al., 1995). Might this capability be common to other aquatic organisms, including fish embryos? Supported by the French space agency (CNES), the Lunar Hatch program plans to study the embryo behavior of European seabass in hypergravity and microgravity in the Gravitational Experimental Platform for Animal Models (GEPAM), a European Space Agency platform to test different gravity environments on animals (Bonnefoy et al., 2021). Exposure to radiation during the space journey will be the last environmental change investigated in future Lunar Hatch program studies: this is probably the parameter with the most impact on fish embryo biology. Knowledge about the effects of space radiation on a variety of organisms has increased over the last decades: for bacteria (Leys et al., 2009), plant and mammalian cells (Arena et al., 2014), and amphibians (Fuma et al., 2014). A ground-based study on the influence of radiation on fish immediately post-hatching was carried out on the ornamental zebrafish (Danio rerio), in which eggs were irradiated with doses ranging from 1 to 1,000 mSv.d−1 for 20 days (Simon et al., 2011). At the stage of 3 days post-hatching, no significant difference in mortality was observed between irradiated eggs and the control. The maximum daily dose was 100 times greater than the total dose astronauts were subjected to during the Apollo 11 mission. These results are consistent with a study in which no significant difference in mortality was observed between 0.8 mGy (the threshold recommended to protect ecosystems) and 570 mGy delivered per day, but the radiation exposure induced accelerated hatching for both doses and a decrease in yolk bag diameter for the highest dose (Gagnaire et al., 2015). In contrast, another study exposing zebrafish embryos to 1, 2.5, 5, 7.5, and 10 mGy of gamma radiation at 3 hpf showed that increasing gamma radiation increased DNA damage, decreased hatching rate, increased median hatching time, decreased body length, increased mortality rate, and increased morphological deformities (Kumar et al., 2017). A higher total dose but spread over time therefore seems to be less harmful than a single high dose concentrated in the early stages of development. Gagnaire et al. also found abnormal development of the spine for individuals subjected to 570 mGy.d−1. These research results on a small fish provide useful information for countermeasures that would need to be implemented on a lunar base. Fish and crew should be protected to reduce cosmic ray damage. Fish embryos could benefit from progress in countermeasure technology developed for humans, but it would be valuable to conduct experiments on the impact of different particles and charges (separate and cumulative) from cosmic radiation on the candidate fish. Conclusion The Lunar Hatch program is investigating the prospects of lunar aquaculture based on a circular food system using a selected species at a specific stage of the lifecycle. It may be of interest to investigate other aquaculture species for other targeted planets or other lifecycle development stages. In the case of the Moon, it is so close to Earth that rearing adults for reproduction would not be worthwhile: a regular shipment of fertilized eggs for monthly generation would avoid costly fish-spawning management on the lunar base. For a more distant destination such as Mars, the embryo stage would be realistic for the first part of the mission, but the total flight would be longer than the duration of embryogenesis. In this case, larval development would need to be considered during the multi-month journey. For farther destinations, studies would need to determine the possibility of rearing broodstock to control the entire biological lifecycle in space. Space aquaculture would provide a valuable food source in addition to those already studied for long-term missions. The diversity of nutrients provided by fish and the benefits for human metabolism may help in the challenges of space medicine, in particular the prevention of cancer caused by long-term exposure to radiation. The activity of fish farming itself could have positive psychological and cognitive effects. Reports about plant-growth chambers on manned missions have described the psychological benefits of working with living organisms in space. An investigation involving social scientists could be conducted to better understand the possible positive benefits of human–animal interaction in space. Vertebrates may recall basic human activities and provide a psychological umbilical cord with the Earth. Modern recirculating aquaculture systems share many characteristics with the closed bioregenerative life-support systems planned for space. Progress in aquaculture technology on land and in space can feed into each other. For example, developments that allow space aquaculture systems to recover and convert waste molecules into edible food could be deployed on Earth to increase food availability while avoiding waste discharge in the environment and preserving biodiversity. Joint efforts to design such waste conversion systems will be applicable above all to human activities on Earth. Like other aspects of BLSS, while space aquaculture is close to being a reality, it is highly dependent on the water and energy available in situ. At the turn of the 20th century, the Russian father of astronautic science Konstantin Tsiolkovsky wrote: “Earth is the cradle of humanity, but one cannot remain in a cradle forever.” Plants and animals are part of the human biosphere and food chain. Space exploration will likely be more successful if humans leave the cradle with a part of their own biosphere and their knowledge of agricultural science, including aquaculture.

#### Food security quickly declining

**Piesse 20** [Mervyn Piesse, Research Manager, Global Food and Water Crises Research Programme, 4 February 2020, FutureDirections, “Global Food and Water Security in 2050: Demographic Change and Increased Demand,” <https://www.futuredirections.org.au/publication/global-food-and-water-security-in-2050-demographic-change-and-increased-demand/>, accessed 8-12-2021]JMK

\*size 2 font is an incredibly long rant about plant-based diets.

Population growth forecasts have contributed to concerns about the world’s ability to produce enough food to feed the larger number of people who are expected to inhabit the planet in 2050. A 2011 study suggests that global crop production will need to more than double by 2050 to ensure that there is enough food to feed the population of almost ten billion, based on crop production in 2005. Global food production has increased at a greater rate than forecast, however, and it is likely that crop production will only need to increase by 25 to 70 per cent from 2014 levels. Between 2005 and 2014 global cereal production increased by 24 per cent while oil crops increased by 39 per cent, due to yield improvements and the expansion of cropped area.

Changes in global food systems have led to nutritional transitions as populations have shifted away from traditional diets towards globalised consumption patterns. A greater proportion of the global population consume a diet based on energy dense, processed foods. Low- and middle-income countries are adopting the “Western diet,” which is high in refined carbohydrates, added sugars, fats and proteins derived from animals. Urbanisation and rising incomes are the main drivers of this global transition.

There is still enough uncultivated land available to bring into production to produce the food for the world’s future population. It is estimated that there is 450 to 1,400 million hectares of non-forested and unprotected land that is suitable for crop agriculture. Most of that land is concentrated in Sub-Saharan Africa, Latin America, Eastern Europe and Central Asia and is often far away from ports and roads, however, which would make it difficult to develop.

Increased food demand and dietary changes are likely to contribute to an intensified use of fertiliser, pesticide and irrigation. To avoid the negative consequences of that intensification, such as the spread of marine hypoxic “dead zones,” pesticide resistance and increased water competition, sustainable forms of agriculture need to be adopted. Water insecurity is not caused by a limitation in global freshwater sources (one estimate suggests that there is about 8.4 million litres of water for each person on earth). As the global population and water supplies are unevenly distributed, however, some regions are more water scarce than others.

At the extremes, responses to those concerns fall into two broad camps: “techno-optimists” and “apocalyptic environmentalists”. The former believe that human ingenuity will always be able to create new technologies that overcome food production limitations, mainly by finding greater efficiencies. The latter suggest that there are planetary boundaries to food production and that any efficiency gain could come at the cost of the natural environment, which will eventually start to undo or threaten any gain. A review of the scientific literature that focusses on three global food security factors, food production, demand and population, indicates that techno-optimism has become the dominant lens through which to view global food supply challenges over the last 50 years. Population, which was the primary concern in the early 1970s, is now the least researched of those three factors.

During the twentieth century new agricultural technologies and growing techniques, which collectively became known as the Green Revolution, lifted crop yields far enough to significantly reduce global hunger. The number of undernourished people has declined by 85 million since 2000. Since 2015, however, the number of undernourished people has increased each year. Currently, about one out of every nine people experience extreme hunger at least once per year. East Africa, the Caribbean and South and West Asia experience the highest prevalence of undernourishment. More than 700 million people were exposed to severe levels of food insecurity in 2018. An additional 1.3 billion people experienced moderate food insecurity, meaning that they did not have regular access to nutritious and sufficient food.

The continuation of hunger in some parts of the world is often explained by difficulties in the distribution of food or a failure to fully adopt the practices or technologies associated with the Green Revolution. There were unintended consequences associated with the Green Revolution, however, as it relied on the application of greater amounts of nitrogen-based fertiliser and water, which has degraded soils and contributed to the overuse of water in some parts of the world.

Several studies (here, here and here, for example) suggest that it is possible to feed ten billion people using current agricultural technologies and techniques and without using more land, water or fertiliser. It will require more people making significant changes to their diet, mainly by adopting a plant-based diet, however, which is unlikely to be popular. Other options are more likely to reduce the environmental impact of intensified agricultural production.

One of the main rationales behind reducing meat consumption is the large amount of human-edible food that is believed to be fed to livestock. It is claimed that one-third of the world’s cereal crops are fed to livestock, but a recent FAO investigation found that 86 per cent of that is made of material that is not currently eaten by humans. The study states that the world’s ‘livestock rely primarily on forages, crop residues and by-products that are not edible to humans’. It also suggests that some livestock systems ‘produce more highly valuable nutrients for humans, such as proteins, than they consume.’ As livestock production does not consume as much human-edible food as once thought, other measures, such as a reduction of food loss and waste, are likely to play a larger role.

It is expected to become more difficult to increase crop yields by 2050. Food production shocks have become more frequent since the 1960s, mainly due to extreme weather events and geopolitical crises. Climate change is expected to result in more volatile growing conditions that are less conducive to food production. Droughts in Africa, where more than half of the world’s population growth is set to occur by 2050, have increased from an average of one every 12.5 years over 1982-2006 to one every 2.5 years over 2007-2016. More than 80 per cent of the economic damage and loss caused by drought is absorbed by the agricultural sector and that is most pronounced in developing countries.

Existing agricultural land could be made more productive through sustainable intensification. That would help to close the “yield gap” between realised and achievable yields. Agricultural yields have been increased without a significant increase in agricultural land use in the past. Between 1961 and 2000, for example, the global population more than doubled and per capita cereal consumption increased by 20 per cent, the harvested area of cereals increased by only seven per cent, however, largely because of increased cropping intensity. While that intensification was assisted by an increase in the use of fertiliser and water, the adoption of new technologies, such as precision agriculture, which utilises resources more accurately and reduces wastage, could ensure that fertiliser and water is better utilised by soils and crops to avoid overuse and runoff.

#### Food Insecurity goes nuclear – escalates multiple hotspots.

Cribb 19 Julian Cribb 8-23-2019 “Food or War” <https://www.cambridge.org/core/books/abs/food-or-war/hotspots-for-food-conflict-in-the-twentyfirst-century/1CD674412E09B8E6F325C9C0A0A6778A> (principal of Julian Cribb & Associates who provide specialist consultancy in the communication of science, agriculture, food, mining, energy and the environment. , His published work includes over 8000 articles, 3000 media releases and eight books. He has received 32 awards for journalism.)//Elmer

Future Food Wars The mounting threat to world peace posed by a food, climate and ecosystem increasingly compromised and unstable was emphasised by the US Director of National Intelligence, Dan Coats, in a briefing to the US Senate in early 2019. 'Global environmental and ecological degradation, as well as climate change, are likely to fuel competition for resources, economic distress, and social discontent through 2019 and beyond', he said. 'Climate hazards such as extreme weather, higher temperatures, droughts, floods, wildfires, storms, sea level rise, soil degradation, and acidifying oceans are intensifying, threatening infrastructure, health, and water and food security. Irreversible damage to ecosystems and habitats will undermine the economic benefits they provide, worsened by air, soil, water, and marine pollution.' Boldly, Coats delivered his warning at a time when the US President, Trump, was attempting to expunge all reference to climate from government documents. 23 Based upon these recent cases of food conflicts, and upon the lessons gleaned from the longer history of the interaction between food and war, several regions of the planet face a greatly heightened risk of conflict towards the mid twentyfirst century. Food wars often start out small, as mere quarrels over grazing rights, access to wells or as one faction trying to control food supplies and markets. However, if not resolved quickly these disputes can quickly escalate into violence, then into civil conflagrations which, if not quelled, can in turn explode into crises that reverberate around the planet in the form of soaring prices, floods of refugees and the involvement of major powers — which in turn carries the risk of transnational war. The danger is magnified by swollen populations, the effects of climate change, depletion of key resources such as water, topsoil and nutrients, the collapse of ecosystem services that support agriculture and fisheries, universal pollution, a widening gap between rich and poor, and the rise of vast megacities unable to feed themselves (Figure 5.3). Each of the world's food 'powderkeg regions' is described below, in ascending order of risk. United States In one sense, food wars have already broken out in the United States, the most overfed country on Earth. Here the issue is chiefly the growing depletion of the nation's mighty ground- water resources, especially in states using it for food production, and the contest over what remains between competing users — farmers, ranchers and Native Americans on the one hand and the oil, gas and mining industry on the other. Concern about the future of US water supplies was aggravated by a series of savage droughts in the early twentyfirst century in the west, south and midwest linked to global climate change and declining snow- pack in the Rocky Mountains, both of which affect not only agriculture but also the rate at which the nation's groundwater reserves recharge. 'Groundwater depletion has been a concern in the Southwest and High Plains for many years, but increased demands on our groundwater resources have overstressed aquifers in many areas of the Nation, not just in arid regions', notes the US Geological Survey.24 Nine US states depend on groundwater for between 50 per cent and 80 per cent of their total freshwater supplies, and five states account for nearly half of the nation's groundwater use. Major US water resources, such as the High Plains aquifers and the Pacific Northwest aquifers have sunk by 30—50 metres (100—150 feet) since exploitation began, imperilling the agricultural industries that rely on them. In the arid south- west, aquifer declines of 100—150 metres have been recorded (Figure 5.4). To take but one case, the famed Ogallala Aquifer in the High Plains region supports cropping industries worth more than US $20 billion a year and was in such a depleted state it would take more than 6000 years to replace by natural infiltration the water drawn from it by farmers in the past 150 years. As it dwindles, some farmers have tried to kick their dependence on ground- water other users, including the growing cities and towns of the region, proceeded to mine it as if there was no tomorrow.25 A study by Kansas State University concluded that so far, 30 per cent of the local groundwater had been extracted and another 39 per cent would be depleted by the mid century on existing trends in withdrawal and recharge.26 Over half the US population relies on groundwater for drinking; both rural and urban America are at risk. Cities such as New Orleans, Houston and Miami face not only rising sea levels — but also sinking land, due to the extraction of underlying ground- water. In Memphis, Tennessee, the aquifer that supplies the city's drinking water has dropped by 20 metres. Growing awareness of the risk of a nation, even one as large and technologically adept as the USA, having insufficient water to grow its food, generate its exports and supply its urban homes has fuelled tensions leading to the eruption of nationwide protests over 'fracking' for oil and gas — a process that can deplete or poison groundwater — and the building -of oil pipe- lines, which have a habit of rupturing and also polluting water resources. The boom in fracking and piping is part of a deliberate US policy to become more self-reliant in fossil fuels.27 Thus, in its anxiety to be independent of overseas energy suppliers, the USA in effect decided to barter away its future food security for current oil security — and the price of this has been a lot of angry farmers, Native Americans and concerned citizens. The depletion of US groundwater coincides with accelerating climate risk, which may raise US temperatures by as much as 4—5 oc by 2100, leading to major losses in soil moisture throughout the US grain belt, and the spread of deserts in the south and west. Food production will also be affected by fiercer storms, bigger floods, more heatwaves, an increase in drought frequency and greater impacts from crop and livestock diseases. In such a context, it is no time to be wasting stored water. The case of the USA is included in the list of world 'hot spots' for future food conflict, not because there is danger of a serious shooting war erupting over water in America in the foreseeable future, but to illustrate that even in technologically advanced countries unforeseen social tensions and crises are on the rise over basic resources like food, land and water and their depletion. This doesn't just happen in Africa or the Middle East. It's a global phenomenon. Furthermore, the USA is the world's largest food exporter and any retreat on its part will have a disproportionate effect on world food price and supply. There is still plenty of time to replan America's food systems and water usage — but, as in the case of fossil fuels and climate, rear-guard action mounted by corporate vested interests and their hired politicians may well paralyse the national will to do it. That is when the US food system could find itself at serious risk, losing access to water in a time of growing climatic disruption, caused by exactly the same forces as those depleting the groundwater: the fossil fuels sector and its political stooges. The probable effect of this will, in the first instance, be a decline in US meat and dairy production accompanied by rising prices and a fall in its feedgrain exports, with domino effects on livestock industries worldwide. The flip-side to this issue is that America's old rival, Russia, is likely to gain in both farmland and water availability as the planet warms through the twentyfirst century — and likewise Canada. Both these countries stand to prosper from a US withdrawal from world food markets, and together they may negate the effects of any US food export shortfalls. Central and South America South America is one of the world's most bountiful continents in terms of food production — but, after decades of improvement, malnutrition is once more on the rise, reaching a new peak of 42.5 million people affected in 2016. 28 'Latin America and the Caribbean used to be a worldwide example in the fight against hunger. We are now following the worrisome global trend', said regional FAO representative Julio Berdegué. 29 Paradoxically, obesity is increasing among Latin American adults, while malnutrition is rising among children. 'Although Latin America and the Caribbean produce enough food to meet the needs of their population, this does not ensure healthy and nutritious diets', the FAO explains. Worsening income inequality, poor access to food and persistent poverty are contributing to the rise in hunger and bad diets, it adds.30 'The impact of climate change in Latin America and the Caribbean will be considerable because of its economic dependence on agriculture, the low adaptive capacity of its population and the geographical location of some of its countries', an FAO report warned.31 Emerging food insecurity in Central and Latin America is being driven by a toxic mixture of failing water supplies, drying farmlands, poverty, maladministration, incompetence and corruption. These issues are exacerbated by climate change, which is making the water supply issue worse for farmers and city people alike in several countries and delivering more weather disasters to agriculture. Mexico has for centuries faced periodic food scarcity, with a tenth of its people today suffering under-nutrition. In 2008 this rose to 18 per cent, leading to outbreaks of political violence. 2 In 2013, 52 million Mexicans were suffering poverty and seven million more faced extreme hunger, despite the attempts of successive governments to remedy the situation. By 2100 northern Mexico is expected to warm by 4—5 oc and southern Mexico by 1.5—2.5 oc. Large parts of the country, including Mexico City, face critical water scarcity. Mexico's cropped area could fall by 40—70 per cent by the 2030s and disappear completely by the end of the century, making it one of the world's countries most at risk from catastrophic climate change and a major potential source of climate refugees.33 The vanishing lakes and glaciers of the high Andes confront montane nations — Bolivia, Peru and Chile especially — with the spectre of growing water scarcity and declining food security. The volume of many glaciers, which provide meltwater to the region's rivers, which in turn irrigate farmland, has halved since 1975.34 Bolivia's second largest water body, the 2000 square kilometres Lake Poopo, dried out completely.35 The loss of water is attributed partly to El Niho droughts, partly to global warming and partly to over-extraction by the mining industries of the region. Chile, with 24,000 glaciers (80 per cent of all those in Latin America) is feeling the effects of their retreat and shrinkage especially, both in large cities such as the capital Santiago, and in irrigation agriculture and energy supply. Chile is rated by the World Resources Institute among the countries most likely to experience extreme water stress by 2040.36 Climate change is producing growing water and food insecurity in the 'dry corridor' of Central America, in countries such as El Salvador, Guatemala and Honduras. Here a combination of drought, major floods and soil erosion is undermining efforts to raise food production and stabilise nutrition. Food production in Venezuela began falling in the 1990s, and by the late 2010s two thirds of the population were malnourished; there was a growing flood of refugees into Colombia and other neighbouring countries. The food crisis has been variously blamed on the Venezuelan government's 'Great Leap Forward' (modelled on that of China — which also caused widespread starvation), a halving in Venezuela's oil export earnings, economic sanctions by the USA, and corruption. However, local scientists such as Nobel Laureate Professor Juan Carlos Sanchez warn that climate impacts are already striking the densely populated coastal regions with increased torrential rains, flooding and mudslides, droughts and hurricanes, while inland areas are drying out and desertifying, leading to crop failures, water scarcity and a tide of climate refugees.37 These factors will tend to deepen food insecurity towards the mid century. Venezuela's climate refugees are already making life more difficult for neighbouring countries such as Colombia. Deforestation in the Brazilian Amazon has, in recent decades, removed around 20 per cent of its total tree cover, replacing it with dry savannah and farmland. At 40 per cent clearance and with continued global warming, scientists anticipate profound changes in the local climate, towards a drying trend, which will hammer the agriculture that has replaced the forest.38 Brazil has already wiped out the once- vast Mata Atlantica forest along its eastern coastline, and this region is now drying, with resultant water stress for both farming and major cities like Säo Paulo. Brazil's outlook for 2100 is for further drying — tied to forest loss as well as global climate change — increased frequency of drought and heatwaves, major fires and acute water scarcity in some regions. Moreover, as the Amazon basin dries out, if will release vast quantities of C02 from its peat swamps and rainforest soils. These are thought to contain in excess of three billion tonnes of carbon and could cause a significant acceleration in global warming, affecting everyone on Earth. 39 Latin America is the world capital of private armies, with as many as 50 major guerrilla groups, paramilitaries, terrorist, indigenous and criminal insurgencies over the past half century exemplified in familiar names like the Sandanistas (Nicaragua), FARC (Colombia) and Shining Path (Peru). 40 Many of these drew their initial inspiration from the international communist movement of the mid twentieth century, while others are right-wing groups set up in opposition to them or else represent land rights movements of disadvantaged groups. However, all these movements rely for oxygen on simmering public discontent with ineffectual or corrupt governments and lack of fair access to food, land and water generally. In other words, the tendency of South and Central America towards internal armed conflict is supercharged significantly by failings in the food system which generate public anger, leading to sympathy and support for anyone seen to be challenging the incumbent regimes. This is not to suggest that feeding every person well would end all insurgencies — but it would certainly take the wind of popular support out of a lot of their sails. In that sense the revolutionary tendency of South America echoes the preconditions for revolution in France and Russia in the eighteenth and twentieth centuries. Central Asia The risk of wars breaking out over water, energy and food insecurity in Central Asia is high.41 Here, the five main players — Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan and Kyrgyzstan — face swelling populations, crumbling Soviet-era infrastructure, flagging resource cooperation, a degrading land- scape, deteriorating food availability and a changing climate. At the heart of the issue and the region's increasingly volatile politics is water: 'Without water in the region's two great rivers — the Syr Darya and the Amu Darya — vital crops in the down- stream agricultural powerhouses would die. Without power, life in the upstream countries would be unbearable in the freezing winters' , wrote Rustam Qobil. Central Asia's water crisis first exploded onto the global consciousness with the drying of the Aral Sea — the world's fourth largest lake — from the mid 1960s43, following the damming and draining of major rivers such as the Amu Darya, Syr Darya and Naryn. It was hastened by a major drought in 200844 exacerbated by climate change, which is melting the 'water tower' of glacial ice stored in the Tien Shan, Pamir and Hindu Kush mountain ranges that feed the region's rivers. The Tien Shan alone holds 10,000 glaciers, all of them in retreat, losing an estimated 223 million cubic metres a year. At such a rate of loss the region's rivers will run dry within a generation.45 Lack of water has already delivered a body blow to Central Asia's efforts to modernise its agriculture, adding further tension to regional disputes over food, land and water. 'Water has always been a major cause of wars and border conflicts in the Central Asian region', policy analyst Fuad Shahbazov warned. This potential for conflict over water has been exacerbated by disputes over the Fergana valley, the region's greatest foodbowl, which underwent a 32 per cent surge in population in barely ten years — while more and more of it turned to desert.46 The Central Asian region is ranked by the World Resources Institute as one of the world's most perilously water-stressed regions to 2040 (Figure 5.6). With their economies hitting rock bottom, corrupt and autocratic governments that prefer to blame others for their problems and growing quarrels over food, land, energy and water, the 'Stans' face 'a perfect storm', Nate Shenkkan wrote in the journal Foreign Policy 47 Increased meddling by Russia and China is augmenting the explosive mix: China regards Central Asia as a key component of its 'Belt and Road' initiative intended to expand its global influence, whereas Russia hopes to lure the region back into its own economic sphere. Their rival investments may help limit some of the problems faced by Central Asia — or they may unlock a fresh cycle of political feuding, turmoil and regime change.48 A 2017 FAO report found 14.3 million people — one in every five — in Central Asia did not have enough to eat and a million faced actual starvation, children especially. It noted that after years of steady improvement, the situation was deteriorating. This combination of intractable and deteriorating factors makes Central Asia a serious internal war risk towards the mid twentyfirst century, with involvement by superpowers raising the danger of international conflict and mass refugee flight. The Middle East The Middle East is the most water-stressed region on Earth (see Figure 5.5 above). It is 'particularly vulnerable to climate change. It is one of the world's most water-scarce and dry regions, with a high dependency on climate-sensitive agriculture and a large share of its population and economic activity in flood-prone urban coastal zones', according to the World Bank. 49 The Middle East — consisting of the 22 countries of the Arab League, Turkey and Iran — has very low levels of natural rainfall to begin with. Most of it has 600 millimetres or less per year and is classed as arid. 'The Middle East and North Africa [MENA] is a global hotspot of unsustainable water use, especially of ground- water. In some countries, more than half of current water withdrawals exceed what is naturally available', the Bank said in a separate report on water scarcity. 50 'The climate is predicted to become even hotter and drier in most of the MENA region. Higher temperatures and reduced precipitation will increase the occurrence of droughts. It is further estimated that an additional 80—100 million people will be exposed by 2025 to water stress', the Bank added. The region's population of 300 million in the late 2010s is forecast to double to 600 million by 2050. Average temperatures are expected to rise by 3—5 oc and rainfall will decrease by around 20 per cent. The result will be vastly increased water stress, accelerated desertification, growing food insecurity and a rise in sea levels displacing tens of millions from densely popu- lated, low-lying areas like the Nile delta.51 The region is deemed highly vulnerable to climate impacts, warns a report by the UN Development Programme. 'Current climate change projections show that by the year 2025, the water supply in the Arab region will be only 15 per cent of levels in 1960. With population growth around 3 per cent annually and deforestation spiking to 4 per cent annually... the region now includes 14 of the world s 20 most water-stressed countries.'52 The Middle Fast/North Africa (MENA) region has 6 per cent of the world's population with only 1.5 per cent of the world's fresh water reserves to share among them. This means that the average citizen already has about a third less water than the minimum necessary for a reasonable existence — many have less than half, and populations are growing rapidly. Coupled with political chaos and ill governance in many countries, growing religious and ethnic tensions between different groups — often based on centuries-old disputes — a widening gap between rich and poor and foreign meddling by the USA, Russia and China, shortages of food, land and water make the Middle East an evident cauldron for conflict in the twentyfirst century. Growing awareness of their food risk has impelled some oil-rich Arab states into an international farm buying spree, purchasing farming, fishing and food processing companies in countries as assorted as South Sudan, Ethiopia, the Philippines, Ukraine, the USA, Poland, Argentina, Australia, Brazil and Morocco. In some food-stressed countries these acquisitions have already led to riots and killings.53 The risk is high that, by exporting its own food—land—water problems worldwide, especially to regions already facing scarcity, the Middle East could propagate conflicts and government collapses around the globe. This is despite the fact that high-tech solar desalination, green energy, hydroponics, aquaponics and other intensive urban food production technologies make it possible for the region to produce far more of its own food locally, if not to be entirely self-sufficient. Dimensions of the growing crisis in the Middle East include the following. Wars have already broken out in Syria and Yemen in which scarcity of food, land and water were prominent among the tensions that led to conflict between competing groups. Food, land and water issues feed into and exacerbate already volatile sentiment over religion, politics, corruption, mismanagement and foreign interference by the USA, China and Russia. The introduction of cheap solar-powered and diesel pumps has accelerated the unsustainable extraction of groundwater throughout the region, notably in countries like Libya, Egypt, Saudi Arabia and Morocco. 54 Turkish building of new dams to monopolise waters flowing across its borders is igniting scarcity and potential for conflict with downstream nations, including Iraq, Iran and Syria. 55 Egypt's lifeline, the Nile, is threatened by Ethiopian plans to dam the Blue Nile, with tensions that some observers consider could lead to a shooting war. 56 There are very low levels of water recycling throughout the region, while water use productivity is about half that of the world as a whole. There is a lack of a sense of citizen responsibility for water and food scarcity throughout the region. Land grabs around the world by oil-rich states are threatening to destabilise food, land and water in other countries and regions, causing conflict. A decline in oil prices and the displacement of oil by the global renewables revolution may leave the region with fewer economic options for solving its problems. There is a risk that acquisition of a nuclear weapon by Iran may set off a nuclear arms race in the region with countries such as Saudi Arabia, Syria and possibly Turkey following suit and Israel rearming to stay in the lead. This would translate potential food, land and water conflicts into the atomic realm. Together these issues, and failure to address their root causes, make the Middle East a fizzing powder keg in the twentyfirst century. The question is when and where, not whether, it explodes — and whether the resulting conflict will involve the use of weapons of mass destruction, including nuclear, thus affecting the entire world. China China is the world's biggest producer, importer and consumer of food. Much of the landmass of the People's Republic of China (PRC) is too mountainous or too arid for farming, but the rich soils of its eastern and southern regions are highly productive provided sufficient water is available and climate impacts are mild. Those, however, are very big 'ifs'. In 1995, American environmentalist Lester R. Brown both Eked and aroused the PRC Communist Party bosses with a small, hard-hitting book entitled Who Will Feed China? Wake-Up Call for a Small Planet.57 In it he posited that Chinese population growth was so far out of control that the then-agricultural system could not keep up, and China would be forced to import vast amounts of grain, to the detriment of food prices and availability worldwide. His fears, so far, have not been realised — not because they were unsoundly based, but because China managed — just — to stay abreast of rising food demand by stabilising and subsidising grain prices, restoring degraded lands, boosting agricultural science and technology, piping water from south to north, developing high-intensity urban farms, buying up foreign farmland worldwide and encouraging young Chinese to leave the country. What Brown didn't anticipate was the economic miracle that made China rich enough to afford all this. However, his essential thesis remains valid: China's food supply will remain on a knife-edge for the entire twentyfirst century, vulnerable especially to water scarcity and climate impacts. If the nation outruns its domestic resources yet still has to eat, it may well be at the expense of others globally. Some western commentators were puzzled when China scrapped its 35-year 'One Child Policy' in 2015, but in fact the policy had done its job, shaving around 300 million people off the projected peak of Chinese population. It was also causing serious imbalances, such as China's huge unmarried male sur- plus. Furthermore, rising urbanisation and household incomes meant Chinese parents no longer wanted large families, as in the past. Policy or no policy, China's birthrate has continued to fall and by 2018 was 1.6 babies per woman — well below replacement, lower than the USA and nearly as low as Germany. Its population was 1.4 billion, but this was growing at barely 0.4 per cent a year, with the growth due at least in part to lengthening life expectancy. 58 For China, female fertility is no longer the key issue. The critical issue is water. And the critical region is the north, where 41 per cent of the population reside. Here surface and ground- waters — which support not only the vast grain and vegetable farming industries of the North China Plain but also burgeoning megacities like Beijing, Tianjin and Shenyang — have been vanishing at an alarming rate. 'In the past 25 years, 28,000 rivers have disappeared. Groundwater has fallen by up to 1—3 metres a year. One consequence: parts of Beijing are subsiding by 11 cm a year. The flow of the Yellow River, water supply to millions, is a tenth of what it was in the 1940s; it often fails to reach the sea. Pollution further curtails supply: in 2017 8.8 per cent of water was unfit even for agricultural or industrial use', the Financial Times reported.59 On the North China Plain, annual consump- tion of water for all uses, including food production, is about 27 billion cubic metres a year — compared with an annual water availability of 22 billion cubic metres, a deficit that is made up by the short-term expedient of mining the region's groundwater. 60 To stave off disaster, the PRC has built a prodigious network of canals and pipelines from the Yangtse River in the water-rich south, to Beijing in the water-starved north. Hailed as a 'lifeline', the South—North Water Transfer Project had two drawbacks: first, the fossil energy required to pump millions of tonnes of water over a thousand kilometres and, second, the fact that while the volume was sufficient to satisfy the burgeoning cities for a time, it could not supply and distribute enough clean water to meet the needs of irrigated farming over so vast a region in the long run, nor meet those of its planned industrial growth.61 Oft-mouthed 'solutions' like desalination or the piping of water from Tibet or Russia face similar drawbacks: demand is too great for the potential supply and the costs, both financial and environmental, prohibitive. China is already among the world's most water-stressed nations. The typical Chinese citizen has a 'water footprint' of 1071 cubic metres a year — three quarters of the world average (1385 cubic metres), and scarcely a third that of the average American (2842 cubic metres).62 Of this water, 62 per cent is used to grow food to feed the Chinese population — and 90 per cent is so polluted it is unfit to drink or use in food processing. Despite massive investment in water infrastructure and new technology, many experts doubt that China can keep pace with the growth in its demand for food, at least within its own borders, chiefly because of water scarcity.63 Adding to the pressure is that China's national five-year plans for industrialisation demand massive amounts more water — demands that may confront China with a stark choice between food and economic growth. 'The Chinese government is moving too slowly towards the Camel Economy. It has plans, incentives for officials; it invests in recycling, irrigation, pollution, drought resistant crops; it leads the world in high voltage transmission (to get hydro, wind and solar energy from the west of China). None of this is sufficient or likely to be in time', the Financial Times opined. As the world's leading carbon emitter, China is more responsible for climate change than any other country. It is also, potentially, more at risk. The main reason, quite simply, is the impact of a warming world on China's water supply — in the form of disappearing rivers, lakes, groundwater and mountain glaciers along with rising sea levels. To this is coupled the threat to agriculture from increasing weather disasters and the loss of ecosystem services from a damaged landscape. 65 China is thus impaled on the horns of a classic dilemma. Without more water it cannot grow its economy sufficiently to pay for the water-conserving and food-producing technologies and infrastructure it needs to feed its people. Having inadvertently unleashed a population explosion with its highly successful conversion to modern farming systems, the challenge for China now is to somehow sustain its food supply through the population peak of the mid twentyfirst century, followed by a managed decline to maybe half of today's numbers by the early twentysecond century. It is far from clear whether the present approach — improving market efficiency, continuing to modernise agricultural production systems, pumping water, trying to control soil and water losses and importing more food from overseas will work. 66 China has pinned its main hopes on technology to boost farm yields and improve water distribution and management. Unfortunately, it has selected the unsustainable American industrial farming model to do this — which involves the massive use of water, toxic chemicals, fertilisers, fossil fuels and machines. This in turn is having dreadful consequences for China's soils, waters, landscapes, food supply, air, climate and consumer health. Serious questions are now being asked whether such an approach is not digging the hole China is in, even deeper. Furthermore, some western analysts are sceptical whether the heavy hand of state control is up to the task of generating the levels of innovation required to feed China sustainably.67 Plan B, which is to purchase food from other countries, or import it from Chinese-owned farming and food ventures around the world, faces similar difficulties. Many of the countries where China is investing in food production themselves face a slow-burning crisis of land degradation, water scarcity, surging populations and swelling local food demand. By exporting its own problems, China is adding to their difficulties. While there may be some truth to the claim that China is helping to modernise food systems in Africa, for example, it is equally clear that the export of food at a time of local shortages could have dire consequences for Africans, leading to wars in Africa and elsewhere. How countries will react to Chinese pressure to export food in the face of their own domestic shortages is, as yet, unclear. If they permit exports, it could prove cata- strophic for their own people and governments — but if they cut them off, it could be equally catastrophic for China. Such a situation cannot be regarded as anything other than a menace to world peace. Around 1640, a series of intense droughts caused widespread crop failures in China, leading to unrest and uprisings which, in 1644, brought down the Ming Dynasty. A serious domestic Chinese food and water crisis today — driven by drought, degradation of land and water and climate change in northern China coupled with failure in food imports — could cause a re-run of history: 'The forthcoming water crisis may impact China's social, economic, and political stability to a great extent', a US Intelligence Assessment found. The adverse impacts of climate change will add extra pressure to existing social and resource stresses.' 68 Such events have the potential to precipitate tens, even hundreds, of millions of emigrants and refugees into countries all over the world, with domino consequences for those countries that receive them. Strategic analysts have speculated that tens of millions of desperate Chinese flooding into eastern Russia, or even India, could lead to war, including the risk of international nuclear exchange. 69 Against such a scenario are the plain facts that China is a technologically advanced society, with the foresight, wealth and capacity to plan and implement nationwide changes and the will, if necessary, to enforce them. Its leaders are clearly alert to the food and water challenge — and its resolution may well depend on the extent of water recycling they are able to achieve. As to whether the PRC can afford the cost of transitioning from an unsustainable to a sustainable food system, all countries have a choice between unproductive military spending and feeding their populace. A choice between food or war. It remains to be seen which investment China favours. However, it is vital to understand that the problem of whether China can feed itself through the twentyfirst century is not purely a Chinese problem. It's a problem, both economic and physical, for the entire planet — and it is thus in everyone's best interest to help solve it. For this reason, China is rated number 3 on this list of potential food war hotspots. Africa Food wars — that is, wars in which food, land and water play a significant contributing role — have been a constant in the story of Africa since the mid twentieth century, indeed, far longer. In a sense, the continent is already a microcosm of the world of the twentyfirst century as climate change and resource scarcity com- bine with rapid population growth to ratchet up the tensions that lead competing groups to fight, whether the superficial distinc- Mons between them are ethnic, religious, social or political. We have examined the particular cases of Rwanda, South Sudan and the Horn of Africa — but there are numerous other African conflicts, insurgencies and ongoing disturbances in which food, land and water are primary or secondary triggers and where famine is often the outcome: Nigeria, Congo, Egypt, Tunisia, Libya, Mali, Chad, the Central African Republic, the Maghreb region of the Sahara, Mozambique, Cote d'Ivoire and Zimbabwe have all experienced conflicts in which issues of access to food, land and water were important drivers and consequences. The trajectory of Africa's population in the first two decades of the twentyfirst century implies that the number of its people could quadruple from 1.2 billion in 2017 to 4.5 billion by 2100 (Figure 5.6). If fulfilled, this would make Africans 41 per cent of the world population by the end of the century. The UN Popula- tion Division's nearer projections are for Africans to outnumber Chinese or Indians at 1.7 billion by 2030, and reach 2.5 billion in 2050, which represents a doubling in the continent's inhabitants in barely 30 years. 70 While African fertility rates (babies per woman) remain high by world standards — 4.5 compared with a global average of 2.4 — they have also fallen steeply, from a peak of 8.5 babies in the 1970s. Furthermore, the picture is uneven with birthrates in most Sub-Saharan countries remaining high (around five to six babies/woman), while those of eight, mainly southern, countries have dropped to replace- ment or below (i.e. under 2.1). As has been the case around the world, birth rates tend to drop rapidly with the spread of urban isation, education and economic growth — whereas countries which slide back into poverty tend to experience rising birth- rates. Food access is a vital ingredient in this dynamic: it has been widely observed that better-fed countries tend to have much lower rates of birth and population growth, possibly because people who are food secure lose fewer infants and children in early life and thus are more open to family planning. So, in a real sense, food sufficiency holds one of the keys to limiting the human population to a level sustainable both for Africa and the planet in general. Forecasting the future of Africa is not easy, given the complexity of the interwoven climatic, social, technological and political issues — and many do not attempt it. However, the relentless optimism of the UN and its food agency, the FAO, is probably not justified by the facts as they are known to science — and may have more to do with not wishing to give offence to African governments or discourage donors than with attempting to accurately analyse what may occur. Even the FAO acknowledges however that food insecurity is rising across Sub-Saharan Africa as well as other parts. In 2017, conflict and insecurity were the major drivers of acute food insecurity in 18 countries and territories where almost 74 million food-insecure people were in need of urgent assistance. Eleven of these countries were in Africa and accounted for 37 million acutely food insecure people; the largest numbers were in northern Nigeria, Demo- cratic Republic of Congo, Somalia and South Sudan the agency said in its Global Report on Food Crises 2018.71 The FAO also noted that almost one in four Africans was undernourished in 2016 — a total of nearly a quarter of a billion people. The rise in undernourishment and food insecurity was linked to the effects of climate change, natural disasters and conflict according to Bukar Tijani, the FAO's assistant director general for Africa. 72 Even the comparatively prosperous nation of South Africa sits on a conflict knife-edge, according to a scientific study: 'Results indicate that the country exceeds its environmental boundaries for biodiversity loss, marine harvesting, freshwater use, and climate change, and that social deprivation was most severe in the areas of safety, income, and employment, which are significant factors in conflict risk', Megan Cole and colleagues found. 73 In the Congo, home to the world's second largest tropical forest, 20 years of civil war had not only slain five million civilians but also decimated the forests and their ecological services on which the nation depended. Researchers found evidence that reducing conflict can also help to reduce environ- mental destruction: 'Peace-building can potentially be a win for nature as well, and.. conservation organizations and govern- ments should be ready to seize conservation opportunities'. 74 As the African population doubles toward the mid century, as its water, soils, forests and economic wealth per capita dwindle, as foreign corporations plunder its riches, as a turbulent climate hammers its herders and farmers — both industrial and traditional — the prospect of Africa resolving existing conflicts and avoiding new ones is receding. The mistake most of the world is making is to imagine this only affects the Africans. The consequences will impact everyone on the planet. A World Bank study has warned that 140 million people will have to leave just three regions of the world as climate refugees before 2050 — and the vast majority of these, some 86 million, would be displaced from their homes in Sub-Saharan Africa. 75 The second decade of the

#### Marine aquaculture solves extinction.

Schubel and Thompson, 19—former adjunct professor, research scientist, and associate director of Johns Hopkins University’s Chesapeake Bay Institute, president and CEO of the Aquarium of the Pacific AND program manager, Seafood for the Future, Aquarium of the Pacific (Jerry and Kimberly, “Farming the Sea: The Only Way to Meet Humanity's Future Food Needs,” GeoHealth, Volume 3, Issue 9, September 2019, Pages 238-244, dml)

As the population and the demand for food grows, so does agriculture's toll on Earth and the ocean. Today, global agriculture consumes 70% of all available freshwater and almost half of Earth's ice‐free land surface (FAO, 2017a; Hooke et al., 2012). It also accounts for one third of all greenhouse gas emissions, with livestock contributing nearly half of this total. In addition, runoff from terrestrial agriculture contributes to the growing prevalence and frequency of dead zones in coastal waters and negatively impacts local marine ecosystems and species.

The United Nations predicts that we will need to produce 50% more food by 2050 to feed another 2.5 billion people (FAO, 2017b). Present agricultural practices cannot scale to meet this demand without a major modification in the way agriculture is implemented. There are not enough freshwater or land resources, and environmental burdens (greenhouse gas emissions, runoff, and soil degradation) will only increase (Duarte et al., 2009; FAO, 2017a; Willett et al., 2019).

The uncertainty and variability that result from climate change makes producing 50% more food challenging. Changes in temperature and precipitation regimes will produce agricultural winners and losers, but on balance global agriculture yields are likely to decrease. A meta‐analysis of more than 1,000 studies on agricultural yields under different climate conditions found that climate change may significantly reduce yields in the long run (Porter et al., 2014). One factor that plays a large role is the decreasing availability of and access to freshwater. Predicted conflicts over this life‐essential resource will impact future agricultural yields, including livestock, in many parts of the world (Duarte et al., 2009; FAO, 2017b).

Livestock, particularly cattle, is an important and growing sector in agriculture. Demand for animal protein in the form of meat, milk, and eggs is increasing. Some factors contributing to this increase in consumption include the growing global population and increasing incomes. The production of these animal protein sources takes a large environmental toll. Raising livestock requires a significant amount of freshwater and land both to support animals directly and to produce the agricultural crops they require as feed. Livestock production also accounts for between 14.5% and 18% of human‐induced greenhouse gas emissions (FAO, 2017b; Searchinger et al., 2018). Most of these emissions are directly emitted by cattle and other ruminants, like sheep and buffalo, which use bacteria in their stomachs to ferment food. The result is the release of methane into the atmosphere when these animals burp (FAO, 2017b).

There are a number of innovations on the horizon that can increase the production of nutritious food from responsible agriculture while minimizing environmental impacts, including precision farming, permaculture, and advancing genetic selection technologies such as GMOs and CRISPR (FAO, 2017b). These innovations will play an important role in creating a sustainable and more climate‐resilient food portfolio, but their capacities to mitigate ecosystem impacts at scale are highly dependent upon changes and transformations at societal and governance levels that may take more time to achieve. In the meantime, countries that have the capacity to increase marine aquaculture responsibly can support much needed changes by integrating responsible land‐based agriculture and aquaculture with ocean‐based aquaculture to meet the food needs of our growing population.

2 Can The Ocean Save Us? It May Have To

The ocean has been an important source of protein for thousands of years. It may even have saved our species from extinction. More than 70,000 years ago, a volcano called Toba erupted in Indonesia. Some contend that it spewed so much ash that the Earth may have gone into the equivalent of a nuclear winter for 6 to 10 years, although this has not been well established (Rampino & Self, 1992; Yost et al., 2018). Temperatures plummeted, and much of life on Earth was extinguished. Some anthropologists contend that Homo sapiens almost went extinct around the same time that Toba erupted as the human population was reduced to only a few thousand breeding pairs (Rampino & Ambrose, 2000). Many lived in caves near Pinnacle Point on the east coast of South Africa, and survived by eating shellfish and finfish. Based on these findings, some scientists contend that the ocean—and seafood—played a role in saving our species from extinction (Marean, 2010, 2012; Marean et al., 2007).

Today, the ocean produces about 17% of the world's per capita consumption of animal protein (FAO, 2018a; Bennett et al., 2018). The ocean's contribution to the total global food supply is far less impressive. While covering 71% of Earth's surface, the world ocean contributes only 2% to the world's food supply on a caloric basis (FAO, 2018b). Protein from seafood is a significant source of high‐quality nutrients and is essential in the diets of some densely populated countries where protein consumption is low (FAO, 2018b; Bennett et al., 2018). In developed countries, like the United States the overall demand is high, but per capita consumption does not meet recommendations from government and health organizations: to eat at least two servings of approximately four ounces of seafood per week to support heart health. Americans eat less than half the recommended amount United States Department of Health and Human Services (USDOH) & United States Department of Agriculture ((USDA), 2015). Eating more seafood—compared to beef, lamb, and pork—to meet our animal protein requirements would have significant human health and environmental benefits (Willett et al., 2019).

3 The Modern Hunter‐Gatherer

It took hundreds of years, but the majority of humans have abandoned their hunter‐gatherer lifestyle, except in the 71% of Earth covered by seawater where the hunter‐gatherer lifestyle persists. We call it fishing, and if left unchecked it threatens to have an effect on marine life similar to what hunter‐gatherers had on terrestrial life. As hunting tools became more sophisticated and the human population grew and expanded, fragmenting and degrading habitat, we drove many of our prey to the brink of extinction and pushed some—like the wooly mammoth, the dodo, the saber tooth tiger, the passenger pigeon, and about 25 other species in North America alone—over the edge (Martin, 1966).

We see ominous signs of what happened on land beginning to happen in the world ocean. To date we have driven a number of ocean species to economic extinction, where their populations are so low it is no longer economically viable to pursue them (Courchamp et al., 2006). In some cases, such as with Atlantic cod, moratoria prohibit or severely restrict harvests in hopes that their populations will rebound and they can once again provide an economically and ecologically sustainable source of food (Hamilton & Butler, 2001). In other cases, we have driven species to ecological extinction, meaning that their populations are so low they no longer play the roles in their ecosystem they once did (Estes et al., 1989). We have even driven a few to biological extinction, meaning they are gone forever (Raup, 1986).

Some countries, including the United States, have established environmentally and economically responsible management of wild‐capture fisheries in their territorial seas. Well‐managed fisheries play an important role in providing nutritious food to the growing and increasingly affluent population (Davis et al., 2016; FAO, 2018b; Hallstrom et al., 2019). They also provide jobs and conserve working waterfronts that are magnets for tourists, but wild‐capture fishing cannot keep pace with the growing demand for seafood. The production from wild seafood harvests have been flat for decades. According to the United Nations Food and Agricultural Organization (FAO), more than 90% of global fish stocks are fished at or above sustainable limits. With appropriate science‐based management that includes setting aside more and larger areas of the ocean for protection, some expansion of wild‐capture harvests is possible, but this expansion will be modest (Bennett et al., 2018; Costello et al., 2016; Edgar et al., 2018; FAO, 2018b; Lester et al., 2009).

Clearly, land‐based agriculture and wild‐capture fisheries cannot provide a consistent supply of food that is scalable to meet the needs of a growing population in a changing climate without increasing environmental impacts. Some forms of aquaculture may also provide ecosystem benefits (Alleway et al., 2018). Aquaculture, or the farming of aquatic organisms, plays a significant role in meeting the growing demand for seafood and already accounts for nearly half of the world's edible seafood supply (FAO, 2018b). Most aquaculture takes place in freshwater systems, which have limited capacity for sustainable growth in an environment where freshwater resources are increasingly limited. Marine aquaculture, or farming the sea, is a promising opportunity to leverage the ocean to complement responsible land‐based agriculture and well‐managed fisheries to increase the global supply of nutritious food with minimal impacts on the ocean and the environment. It must be done using the best and most appropriate science and technology (Lester, Gentry, et al., 2018).

4 Moving Food Production to the Sea

The world ocean is the largest single component in Earth's life support system. We rely on it for essential ecosystem services. The delivery of those services depends upon having healthy, productive, and diverse ecosystems. The ocean provides opportunities for expanding the production of food while relieving pressures on wildlife and natural ecosystem functions on land, which are experiencing the fastest rates of extinction because of habitat loss (Cardinale et al., 2012; Diaz et al., 2019; Froehlich et al., 2017; Powers & Jetz, 2019; Waite et al., 2014). Responsibly farming in the sea can benefit society and minimize unfavorable impacts in order to sustain healthy ocean ecosystems (Lester, Gentry, et al., 2018).

Marine aquaculture requires little land and freshwater, most of which is associated with producing feed inputs and processing (Froehlich, Runge, et al., 2018). It results in fewer greenhouse gas emissions compared to land‐based animal agriculture (Davis et al., 2016; Waite et al., 2014). Shellfish and seaweed aquaculture can even provide ecosystem services, such as cleaning the water, stabilizing shorelines, and storing CO2 (Alleway et al., 2018). Requirements for terrestrial feed inputs are expected to diminish with improving technology for open‐ocean seaweed production and fermentation. Despite historic reliance on wild fish, the most current feed formulations for fish farms have significantly reduced the fish meal component through replacement with fish wastes, plant material, insects, rendered animal proteins, microbial proteins, and algal oils. These and other innovations provide feed that are healthful to the fish, maintain the desired seafood qualities consumers look for, and reduce the strain of aquaculture production on environmental resources.

#### Scenario 2 – Neutrinos:

#### Earth’s Atmosphere limits Neutrino Research – only a Moon base solves.

Crawford 12, I. A., et al. "Back to the Moon: The scientific rationale for resuming lunar surface exploration." Planetary and Space Science 74.1 (2012): 3-14. (Department of Earth and Planetary Sciences, Birkbeck College)//Elmer

A natural area to use the Moon as a platform for performing scientific experiments is astronomy (for summaries see, e.g., Burns et al., 1990; Livio, 2006; Crawford and Zarnecki, 2008; Jester and Falcke, 2009). Almost the entire electromagnetic spectrum is currently being used to study the universe from radio to high-energy gamma ray emission. Different frequencies typically relate to different physical processes, and consequently the universe looks markedly different in optical, infrared, or radio wavelengths. Hence, during the last century modern telescopes have diversified and evolved enormously, fundamentally changing our view of the universe and our place therein. Due to their ever increasing sensitivity, which allows one to peer deeper and deeper into the earliest phases of the cosmos, the requirements for telescope sites have become more and more extreme: one simply needs the best possible observing conditions. The most important factors here are light pollution (at the relevant frequencies) and distortions due to the atmosphere. Light pollution is generally caused by any form of civilization, thereby pushing observatories to more and more remote locations. Detrimental effects of the atmosphere include: • temporary effects such as clouds and water vapour, which temporarily absorb and disturb optical or high-frequency radio radiation, • turbulence in the ionosphere or troposphere, which distorts radio or optical wave fronts, thereby severely degrading the image quality, • air glow, which can overpower sensitive infrared observations, • total absorption of radiation, e.g., of very low-frequency radio, infrared, X-ray, and gamma-ray radiation. The best – and in many cases only – remedy is to observe from dry deserts, high mountains, or from space. Two of the most remote, but also most exquisite, astronomical sites on Earth are the Atacama desert and Antarctica. The former currently hosts some of the world’s largest telescopes, including ESO’s 8m-class Very Large Telescopes (VLT), the ALMA sub-mm-wave radio telescope, and in the future probably also the ~40 m diameter European Extremely Large Telescope (E-ELT; see http:// www.eso.org). A century after its initial exploration, Antarctica now also hosts a number of somewhat smaller telescopes (e.g., the South Pole Telescope, Carlstrom et al., 2011) as well as the giant IceCube detector. IceCube is the world’s largest neutrino observatory, using the ice itself as detector material (e.g., Abbasi et al., 2011). The Moon would be a logical next step in the quest for the most suitable sites to be used for astronomy. An important secondary important factor in selecting a site, however, is the available infrastructure: How accessible is the site for people and material? How does one obtain power and how good is the data connection? Already for Antarctica this poses serious constraints, and it took a long time until this continent became useful for scientific exploitation. It is needless to say that the Moon is even more difficult to reach. Hence, like Antarctica, any significant exploitation of the Moon requires a developed infrastructure – something that would likely become available only in conjunction with human exploration of the Moon. Even then one has to assess how unique and useful the Moon is for astronomy in the first place. After all, the International Space Station (ISS), while having a well-developed infrastructure available, is not used for telescopes; its small, relatively unstable platform in low Earth orbit (LEO) is simply too poor a telescope site to be competitive. Hence, the vast majority of space-based telescopes have been associated with free-flying satellites. Of course, some of these satellites, most notably the Hubble Space Telescope (HST), benefited from the heavy lift capabilities of the Space Shuttle and the servicing possibilities the human space flight program offered (NRC, 2005). Indeed, it is interesting to note that the one human-serviced space telescope, HST, is in fact the most productive of all astronomy space missions even many years after its launch (see Tables 4 and 6 in Trimble and Ceja, 2008; HST produced 1063 papers in the time frame 2001-2003, compared to 724 for Chandra, the next most productive). So, the question to ask is: Which type of telescopes would uniquely benefit from a lunar surface location? This question has been addressed in a couple of workshops and scientific roadmaps in recent years (Falcke et al., 2006; Livio, 2006; NRC, 2007; Crawford and Zarnecki, 2008; Worms et al., 2009). In the following section we try to synthesize these findings. 4.2 Which astronomy? There is a wide consensus that a low-frequency radio telescope (i.e. a radio telescope operating at frequencies below 30-100 MHz) would be the highest priority (e.g., Jester and Falcke, 2009; Burns et al., 2009). Radio waves at these frequencies are seriously distorted by the Earth’s ionosphere and completely absorbed or reflected at frequencies below 10-30 MHz. Hence, the low-frequency universe is the last uncharted part of the electromagnetic spectrum, and a lunar infrastructure would greatly benefit its exploration. Of particular relevance for science here is the investigation of the “dark ages” of the universe. This is the epoch several hundred million years after the big bang, but before the formation of the first stars and black holes, when the cosmos was mainly filled with dark matter and neutral hydrogen. This epoch contains still pristine information of the state of the big bang and can essentially only be observed through radio emission from atomic hydrogen red-shifted to several tens of MHz. The best location to study this treasure trove of cosmology (Loeb and Zaldariaga 2004) would indeed be on the lunar far-side.

#### The Moon is key for Neutrino Research – would be involved in any return to the Moon.

Wilson 92, T. L. "Neutrino Astronomy of the Moon." Lunar and Planetary Science Conference. Vol. 23. 1992. https://www.lpi.usra.edu/meetings/lpsc1992/pdf/1757.pdf (Thomas L. Wilson, NASA Johnson Space CenterISN1)//Elmer

The notion of conducting neutrino astronomy on the Moon has had a very brief history [I-91. The case has even been presented [7] that the ultimate future of neutrino astronomy in the 21st Century may be on the Moon. A recent NASA workshop at Stanford University [6] clearly demonstrated that the physics community supports a return to the Moon, provided its justification is a strong scientific initiative directed at taking advantage of the lower background ambient magnetic fields than on Earth and the absence of an appreciable atmosphere. Several significant issues in particle physics, such as searches for proton decay and measurement of the neutron's electric dipole moment, are background-limited on Earth. Similarly, the Earth's stratosphere is a source of considerable noise in neutrino astronomy on Earth [6,9]. The Moon, in contrast, ostensibly may offer a viable advantage in both of these cases if its backgrounds are appreciably lower as they appear to be. The proposal for a neutrino detector at a lunar base, then, represents an important shift in emphasis towards fundamental physics research in space, as a part of NASA's initiative to re-establish a permanent presence on the Moon. Such a detector would bolster not only the science of neutrino astronomy and its role in basic astrophysics as a neutrino telescope, but would also enhance our fundamental understanding of the physics of the Universe. It is conceivable that long-baseline neutrino oscillations experiments could be conducted between Earth-based accelerators [10,6] and a lunar base neutrino detector. The first round of scientific experiment candidates for a lunar outpost, in fact, includes a lunar neutrino telescope [ll] although any such strategy is still under study. In this regard, neutrino and antineutrino spectra as might be seen on the Moon's surface have been published [6,1-31. The critical issue of prompt neutrino production by decay of charmed mesons has been studied [3,S], but the branching ratios have changed due to further refinement of Earth-based accelerator experiments and these analyses may require additional work. The charm production issue is particularly important because it background-limits a lunar observatory. Furthermore, this occurs in the 1 MeV portion of the neutrino spectrum, right where grand unification in particle physics has been predicting proton decay. Another analysis [12] of Earth-based neutrino astronomy has attempted to illustrate the full spectrum as might be observed from the surface of the Earth, including the (presently undetectable) relic neutrinos left over from the Big Bang [13,14]. This spectrum is amended and presented here (Figure 1) to include the antineutrino luminosity of the Moon [6,15] produced by its natural radioactivity. Charm [I51 is not presented, and it may have overriding significance. This view of the neutrino Universe from the surface of the Moon is important in the assessment and scientific justification for such a detector at a lunar base. The Earth has many advantages in neutrino astronomy because grand-scale neutrino detectors are already in use there, such as in the ongoing radiochemical studies [16] of solar neutrinos. The Moon, on the other hand, clearly has advantages illustrated in Figure 1 due to the lack of in situ atmospheric neutrinos [6,9] and the absence of nuclear reactor antineutrino fluxes which are beginning to complicate antineutrino astronomy's access on Earth to portions of supernovae spectra in astrophysics. The recent study of active galactic nuclei (AGN) neutrinos [17, 181 as another interesting astrophysical source are not presented.

#### Neutrino Research key to Nuclear Detection that deters Proliferation – key to determine military usages.

Lee 20 Thomas Lee "Can tiny, invisible particles help stop the spread of nuclear weapons?" <https://engineering.berkeley.edu/news/2020/03/can-tiny-invisible-particles-help-stop-the-spread-of-nuclear-weapons/> (Associate Adjunct Professor, Research Scientist Operations & IT Management.)//Elmer

The key to preventing nuclear proliferation may depend on a little bit of ghost hunting. Scientists have long been interested in a device that can detect neutrinos, ghost-like particles that have no electric charge and nearly no mass — and therefore can pass through matter. Now, researchers are closer than ever to deploying technology that can spot those elusive subatomic particles and, in doing so, alert international authorities to the illicit production of plutonium, a key fuel for nuclear bombs. The technology may provide a “way to monitor the plutonium content in a nuclear reactor in real time that we just don’t have right now,” said Bethany Goldblum (M.S.’05, Ph.D.’07 NE), a top researcher with UC Berkeley’s Department of Nuclear Engineering. Goldblum, the executive director of the Berkeley-based Nuclear Science and Security Consortium, co-wrote a study published this week in the Review of Modern Physics that examines the feasibility of neutrino detectors in nuclear nonproliferation efforts. The study’s co-authors include Adam Bernstein and Nathaniel Bowden from Lawrence Livermore National Laboratory, Patrick Huber from Virginia Tech, Igor Jovanovic from the University of Michigan and John Mattingly from North Carolina State University. The study ultimately concludes that such technology deployed outside nuclear reactors could prove effective in ensuring that countries are not making weapons-related material under the guise of peaceful civilian energy production. The report also advances the idea that researchers could one day use the technology to discover or exclude the presence of reactors at distances of a few hundred kilometers. “Over several decades, physicists have conceived many ideas for using ﬁssion neutrinos in nuclear security,” the study says. “Some ideas remain in the realm of pen and paper, constrained by basic physical and practical considerations. For other concepts, demonstrated technology is catching up with real opportunities.” The ghost particle Neutrinos are the most abundant particles in the universe, having been formed by large nuclear explosions like the Big Bang, supernovas and the fusion process that happens inside the sun. They travel near the speed of light, have little mass and carry no electric charge. Because of these attributes, neutrinos can pass through matter and are incredibly difficult to detect, which is why scientists often refer to them as “ghost particles.” For example, if 10 trillion neutrinos struck the Earth, all but one would pass through the planet without having interacted with anything at all. In 1956, Clyde Cowen and Frederick Reins, two scientists at the Los Alamos National Laboratory in New Mexico, confirmed the neutrino’s existence, work that eventually earned the Nobel Prize in Physics. The duo placed two large water tanks near a nuclear reactor, which produces electron antineutrinos in huge quantities, as part of the fission process. As it turns out, neutrinos can collide with protons in the water and produce a neutron and a positron through a process called inverse beta decay. When the positron moves through the water, it produces a flash of light that special sensors can detect. Up to this point, scientists were primarily interested in finding neutrinos because the particles might offer clues to the universe’s origin and the formation of stars and galaxies. But starting around the turn of the 21st century, the idea that neutrino detectors could be used in nuclear nonproliferation efforts started to gain real traction. In 2000, Adam Bernstein, then a postdoctoral fellow at the Sandia National Laboratory in Livermore, California, wrote a paper exploring the idea of using detectors filled with purified water to spot neutrinos produced from nuclear explosions. In many ways, water is a great medium to detect neutrinos because it is easy to purify, cheap and is transparent to light produced by neutrinos colliding with water molecules. The key would be to build detectors big enough to hold enough water to see the neutrino signal above background radiation. However, finding neutrinos in water is still pretty hard. Bernstein found that adding small amounts of gadolinium — a rare earth metal with unusual nuclear properties — to the water could significantly boost the detector’s chances of spotting neutrinos. In gadolinium-doped water, neutrino interactions produce a much stronger signal than neutrinos in water alone. Bernstein eventually abandoned the idea to monitor explosions because the cost and size of such neutrino detectors would make the technology impractical, especially compared to existing, cheaper technologies like seismic detectors, he said. Instead, Bernstein turned his attention to using the gadolinium-doped technology to catch neutrinos from nuclear reactors. “Since we’re still mostly using water, it is possible to build large detectors, up to 100 kilotons in size or more, to spot these reactor neutrinos,” said Bernstein, now a staff physicist at the Lawrence Livermore National Laboratory (LLNL) and director of the lab’s Rare Event Detection group in the Nuclear and Chemical Sciences division. “The neutrino signature would stand out much more readily above background radiation even in a big detector,” he said. LLNL is the lead laboratory for a proposed United States/United Kingdom experiment, called WATCHMAN, to demonstrate remote monitoring of nuclear reactors using a kiloton-scale antineutrino detector. This experiment has already “exceeded my expectations,” Bernstein said. “The idea that the nonproliferation community might one day be able to use this technology that until now has been the exclusive province of fundamental science is an exciting motivation for this work.” Halting the spread of nukes Since 1970, nearly 200 nations signed the landmark Treaty of the Non-Proliferation of Nuclear Weapons (NPT), which seeks to limit the spread of nuclear weapons. Through a combination of remote monitoring and on–the–ground inspections, containment and surveillance, the International Atomic Energy Agency (IAEA) commands plenty of tools to figure out if countries are using nuclear energy for peaceful purposes, Goldblum said. But what happens if the line between civilian and military use of nuclear energy is not so clear? For example, the United States has long accused Iran of trying to make nuclear weapons, but Iran says it wants to develop nuclear capabilities for civilian power generation. The knowledge to construct a nuclear bomb is actually pretty well known. The hard part is getting enough materials — either enriched uranium or plutonium — to fuel the weapon. A country can reprocess the spent fuel from a civilian nuclear reactor and extract plutonium for a weapon. And a nuclear bomb only requires about 10 kilograms of plutonium. The so-called “dual-use” capabilities of nuclear reactors presents a significant challenge to the IAEA. “None of the countries now embarking on civil nuclear power programs say they are planning to acquire reprocessing capabilities,” according to a 2017 report by the Brookings Institute think tank. “But many of them are unwilling to forswear what they consider to be their ‘right’ eventually to have dual-use capabilities.” The neutrino detection technology could offer a solution. In addition to the large systems like WATCHMAN, scientists have constructed much smaller detectors that can be deployed close to reactor cores — provided operators allow such access. Optimizing reactor power levels to produce plutonium, a telltale sign that a country is trying to build a bomb, will change the rate and energy spectrum of antineutrinos that a device parked outside of the reactor can detect. And since these particles can pass through matter, the operator can’t shield the reactor’s release of antineutrinos the same way lead blocks X-rays. So if a country wants to operate a civilian nuclear power program, an antineutrino detector could provide an effective tool to continuously verify the reactor is only producing energy for peaceful purposes. For now, a detector must stay within tens of meters of the reactor to be effective. But in the future, could such technology spot antineutrinos from longer distances and even across borders? For distances 100 kilometers or beyond, the Review of Modern Physics study shows detectors would need to be 10 to 100 times bigger than WATCHMAN. But researchers hope WATCHMAN will demonstrate the basic technology and provide a platform for study of a range of possible enhancements to improve standoff and overall sensitivity. And in any case, the mere knowledge that such technology has become a reality could prove to be a powerful deterrent to nuclear proliferation in itself.

#### Proliferation risks unravelling now due to inability to determine peaceful and military nuclear development.

Dalton and Levite 22 Toby Dalton and Ariel Levite 1-13-2022 "The Nonproliferation Regime is Breaking" <https://archive.is/MQ4sC#selection-1881.0-1917.304> (TOBY DALTON is Senior Fellow and Co-Director of the Nuclear Policy Program at the Carnegie Endowment for International Peace. ARIEL (ELI) LEVITE is Senior Fellow in the Nuclear Policy Program and Cyber Policy Initiative at the Carnegie Endowment for International Peace.)//Elmer

The global system to prevent nuclear proliferation and promote disarmament is beginning to fray. Although the nonproliferation regime has held together for more than half a century, more countries are acquiring sensitive nuclear material and technology through illicit acquisition and preferential trade. In May 2021, for instance, the International Atomic Energy Agency (IAEA) reported that Iran had accumulated ten kilograms of highly enriched uranium and severely restricted access to its nuclear sites. And in October 2021, Australia, the United Kingdom, and the United States announced a new strategic partnership (AUKUS) that will make Australia the first ever nonnuclear state to receive highly enriched fuel for nuclear-powered submarines. It is unlikely Australia would divert this uranium to make bombs, but it establishes a dangerous precedent. These two cases typify the growing challenges faced by the nonproliferation system. Historically, the framework set in place by the 1970 Nuclear Nonproliferation Treaty (NPT) relied on development limits and international monitoring of uranium enrichment and plutonium reprocessing to succeed. But the spread of these sensitive nuclear materials and technologies is substantially degrading both processes. It is increasingly difficult to distinguish between nuclear programs designed for peaceful purposes and those that aim to yield bombs. The IAEA toolkit to detect concerning activity, flag it, and address it diplomatically risks obsolescence. To restore the nonproliferation regime’s role as a bulwark of global stability, international nonproliferation institutions and states need new ways to track and tackle the development of nuclear weapons. This requires an innovative approach to monitoring and constraining dangerous activity. But given that more countries are acquiring or producing highly enriched uranium, material constraints alone are not enough. Monitors will need fresh tools to credibly track additional indicators of potential bomb activity that are hard to pass off as peaceful in nature, such as weaponization: the development and manufacture of nuclear warheads for missiles or other delivery vehicles. Monitoring this kind of activity, in particular, goes beyond the traditional focus of nuclear observers, but it may now offer the best, most reliable way to know whether states are trying to acquire nuclear weapons. Given the global rise in nuclear activity, the world should move quickly to create such a system. When existing powers are less able to prevent uranium enrichment—and even hand over highly enriched material to other countries—it incentivizes competitors to double down on their programs. When new states develop bombs, it further encourages proliferation. Especially in an era of growing geopolitical competition, the international community needs more indicative information on the spread of nuclear weapons so that diplomacy can head off destabilizing proliferation and arms races. SHIELDING THE WORLD The NPT is the cornerstone of the nonproliferation order. It requires that nonnuclear states avoid acquiring weapons (Article II), allows all states access to nuclear technology for peaceful purposes (Article IV), and commits the signatories with nuclear weapons—China, France, Russia, the United Kingdom, and the United States—to eventually disarm (Article VI). In practice, this regime limits state possession of and the operation of technology used to produce the fissile materials needed for nuclear weapons: highly enriched uranium and plutonium. And it empowers the IAEA to stringently scrutinize nuclear research and energy programs, enforce nuclear safeguards, and detect clandestine production. Although its powers of enforcement are limited, the NPT has endured due to a combination of IAEA monitoring, strict nuclear trade regulations by multilateral institutions, and commitments by individual member states to abide by the rules. The United States has historically played an important role in leading and augmenting this regime, mostly with the Soviet Union and later with Russia. To uphold the NPT bargain, Washington cooperated with many partner countries through the Atoms for Peace program, sharing technology and materials to advance nuclear energy and research in states that swore off atomic weapons. U.S. agencies also operated programs to constrain the spread of enriched uranium and nuclear production technology, promote transparency in civilian nuclear material, and convert research reactors from high- to low-enriched fuel. By doing so, Washington further slowed the accumulation of fissile and sensitive technology. Other nuclear states supported or at least acceded to these efforts, tightly restricting the flow of key materials and technologies. The system isn’t perfect. There are inherent tensions in the NPT bargain, which allows some states to hold weapons while banning others from acquiring them. The world has experienced periodic proliferation crises that exposed gaping holes in the regime, such as in 1991, when observers discovered that Iraq had a clandestine program for producing nuclear weapons. Sometimes, the NPT has failed to stop weapons development altogether, as happened in North Korea, which withdrew from the treaty when its program was exposed. And three nuclear-armed states—India, presumably Israel, and Pakistan—never joined the NPT. But remarkably, this package has generally held together for decades. Most countries that at one time had nuclear weapons aspirations walked them back, such as South Korea, Sweden, and Switzerland. South Africa voluntarily disarmed, dismantling the six nuclear bombs it had secretly built, and joined the NPT as a nonnuclear state. The world averted close calls, including one resulting from the demise of the Soviet Union, which could have easily yielded four nuclear states instead of one, and another in Iran, which was stopped en route in 2003. If anything, the norm against proliferation has grown stronger over time. Today, only six states without nuclear weapons have the indigenous capability to produce fissile materials—Argentina, Brazil, Germany, Iran, Japan, and the Netherlands—a testament to the efficacy of the regime. But there are multiple signs that this record may not continue. DANGEROUS DECAY Some of the recent problems with the nonproliferation system derive from the stalled progress toward nuclear disarmament by states with nuclear weapons. After Russia and the United States dramatically slashed their Cold War nuclear arsenals by retiring obsolete systems, arms reductions have come to a standstill in both countries in the last decade. Now, they are modernizing their arsenals, as are China, India, Pakistan, and the United Kingdom. This has prompted many nonnuclear states to push forward a nominally complementary but practically competing UN Treaty on the Prohibition of Nuclear Weapons. (The treaty calls for a categorical ban on the possession of nuclear weapons by the signatories, and it has been rejected by all nuclear weapons states and their allies.) Other issues come from the behavior of nuclear states outside the system, most problematically North Korea. But the most worrisome problem is that the barrier between peaceful nuclear activity and weapons development is eroding. Most of the damaging erosion has been done by the weapons states themselves, via ad hoc arrangements to advance other strategic interests. Notably, the 2005 U.S.-Indian nuclear deal, endorsed in 2008 by the Nuclear Suppliers Group—one of the principal institutions that regulates nuclear sales—enabled the United States and others to trade technology with India alongside carve-outs that permitted unsafeguarded Indian nuclear activity for weapons development. Then, the NPT’s 2010 Review Conference affirmed that states pursuing nuclear energy had an unconditional right to fully access nuclear technology, regardless of necessity. The 2015 Iran nuclear deal, the Joint Comprehensive Plan of Action, capped Iran’s uranium enrichment program but walked back an earlier understanding (in the preliminary 2013 Joint Plan of Action) that Iranian enrichment activities would be limited to what Tehran needed for its peaceful program. Both the United States and Iran have since undermined the deal, leaving Iran, according to IAEA Director General Rafael Grossi, enriching uranium to concentrations that “only countries making bombs are reaching.” There are other prominent carve-outs in the system. In 2010, China violated supplier rules by agreeing to construct additional nuclear power reactors in Pakistan, and in 2010 and 2017, Russia signed nuclear deals with Turkey and Egypt, respectively, without requiring (as far as is publicly known) that Ankara or Cairo forego developing fissile materials. Washington’s efforts to promote a “gold standard” for nuclear trade, in which recipients renounce the ability to produce enriched plutonium and uranium, foundered after it was introduced, in 2009, due to opposition from most prospective clients, including Saudi Arabia, and the U.S. government’s own desire to revitalize the domestic nuclear industry through power plant exports. Collectively, this decay in the NPT’s rules has made it easier for nonnuclear states to obtain fissile materials, blurring the primary distinction between peaceful nuclear programs and military ones. Countries with weapons aspirations can now more easily hide their ambitions—and progress—in plain sight.

#### Nuclear Proliferation causes Nuclear War.

Kroenig 15(Matthew Kroenig; Associate Professor and International Relations Field Chair in the Department of Government and School of Foreign Service at Georgetown University; 2015, “The History of Proliferation Optimism: Does It Have a Future?”; *Journal of Strategic Studies*, Volume 38, Issue 1-2)//Re-cut by Elmer

The spread of nuclear weapons poses at least six severe threats to international peace and security including: nuclear war, nuclear terrorism, global and regional instability, constrained US freedom of action, weakened alliances, and further nuclear proliferation. Each of these threats has received extensive treatment elsewhere and this review is not intended to replicate or even necessarily to improve upon these previous efforts. Rather the goals of this section are more modest: to usefully bring together and recap the many reasons why we should be pessimistic about the likely consequences of nuclear proliferation. Many of these threats will be illuminated with a discussion of a case of much contemporary concern: Iran’s advanced nuclear program. Nuclear War The greatest threat posed by the spread of nuclear weapons is nuclear war. The more states in possession of nuclear weapons, the greater the probability that somewhere, someday, there will be a catastrophic nuclear war. To date, nuclear weapons have only been used in warfare once. In 1945, the United States used nuclear weapons on Hiroshima and Nagasaki, bringing World War II to a close. Many analysts point to the 65-plus-year tradition of nuclear non-use as evidence that nuclear weapons are unusable, but it would be naïve to think that nuclear weapons will never be used again simply because they have not been used for some time. After all, analysts in the 1990s argued that worldwide economic downturns like the Great Depression were a thing of the past, only to be surprised by the dot-com bubble bursting later in the decade and the Great Recession of the late 2000s.48 This author, for one, would be surprised if nuclear weapons are not used again sometime in his lifetime. Before reaching a state of MAD, new nuclear states go through a transition period in which they lack a secure-second strike capability. In this context, one or both states might believe that it has an incentive to use nuclear weapons first. For example, if Iran acquires nuclear weapons, neither Iran, nor its nuclear-armed rival, Israel, will have a secure, second-strike capability. Even though it is believed to have a large arsenal, given its small size and lack of strategic depth, Israel might not be confident that it could absorb a nuclear strike and respond with a devastating counterstrike. Similarly, Iran might eventually be able to build a large and survivable nuclear arsenal, but, when it first crosses the nuclear threshold, Tehran will have a small and vulnerable nuclear force. In these pre-MAD situations, there are at least three ways that nuclear war could occur. First, the state with the nuclear advantage might believe it has a splendid first strike capability. In a crisis, Israel might, therefore, decide to launch a preventive nuclear strike to disarm Iran’s nuclear capabilities. Indeed, this incentive might be further increased by Israel’s aggressive strategic culture that emphasizes preemptive action. Second, the state with a small and vulnerable nuclear arsenal, in this case Iran, might feel use them or lose them pressures. That is, in a crisis, Iran might decide to strike first rather than risk having its entire nuclear arsenal destroyed. Third, as Thomas Schelling has argued, nuclear war could result due to the reciprocal fear of surprise attack.49 If there are advantages to striking first, one state might start a nuclear war in the belief that war is inevitable and that it would be better to go first than to go second. Fortunately, there is no historic evidence of this dynamic occurring in a nuclear context, but it is still possible. In an Israeli–Iranian crisis, for example, Israel and Iran might both prefer to avoid a nuclear war, but decide to strike first rather than suffer a devastating first attack from an opponent. Even in a world of MAD, however, when both sides have secure, second-strike capabilities, there is still a risk of nuclear war. Rational deterrence theory assumes nuclear-armed states are governed by rational leaders who would not intentionally launch a suicidal nuclear war. This assumption appears to have applied to past and current nuclear powers, but there is no guarantee that it will continue to hold in the future. Iran’s theocratic government, despite its inflammatory rhetoric, has followed a fairly pragmatic foreign policy since 1979, but it contains leaders who hold millenarian religious worldviews and could one day ascend to power. We cannot rule out the possibility that, as nuclear weapons continue to spread, some leader somewhere will choose to launch a nuclear war, knowing full well that it could result in self-destruction. One does not need to resort to irrationality, however, to imagine nuclear war under MAD. Nuclear weapons may deter leaders from intentionally launching full-scale wars, but they do not mean the end of international politics. As was discussed above, nuclear-armed states still have conflicts of interest and leaders still seek to coerce nuclear-armed adversaries. Leaders might, therefore, choose to launch a limited nuclear war.50 This strategy might be especially attractive to states in a position of conventional inferiority that might have an incentive to escalate a crisis quickly to the nuclear level. During the Cold War, the United States planned to use nuclear weapons first to stop a Soviet invasion of Western Europe given NATO’s conventional inferiority.51 As Russia’s conventional power has deteriorated since the end of the Cold War, Moscow has come to rely more heavily on nuclear weapons in its military doctrine. Indeed, Russian strategy calls for the use of nuclear weapons early in a conflict (something that most Western strategists would consider to be escalatory) as a way to de-escalate a crisis. Similarly, Pakistan’s military plans for nuclear use in the event of an invasion from conventionally stronger India. And finally, Chinese generals openly talk about the possibility of nuclear use against a US superpower in a possible East Asia contingency. Second, as was also discussed above, leaders can make a ‘threat that leaves something to chance’.52 They can initiate a nuclear crisis. By playing these risky games of nuclear brinkmanship, states can increase the risk of nuclear war in an attempt to force a less resolved adversary to back down. Historical crises have not resulted in nuclear war, but many of them, including the 1962 Cuban Missile Crisis, have come close. And scholars have documented historical incidents when accidents nearly led to war.53 When we think about future nuclear crisis dyads, such as Iran and Israel, with fewer sources of stability than existed during the Cold War, we can see that there is a real risk that a future crisis could result in a devastating nuclear exchange. Nuclear Terrorism The spread of nuclear weapons also increases the risk of nuclear terrorism.54 While September 11th was one of the greatest tragedies in American history, it would have been much worse had Osama Bin Laden possessed nuclear weapons. Bin Laden declared it a ‘religious duty’ for Al- Qa’eda to acquire nuclear weapons and radical clerics have issued fatwas declaring it permissible to use nuclear weapons in Jihad against the West.55 Unlike states, which can be more easily deterred, there is little doubt that if terrorists acquired nuclear weapons, they would use them.56 Indeed, in recent years, many US politicians and security analysts have argued that nuclear terrorism poses the greatest threat to US national security.57 Analysts have pointed out the tremendous hurdles that terrorists would have to overcome in order to acquire nuclear weapons.58 Nevertheless, as nuclear weapons spread, the possibility that they will eventually fall into terrorist hands increases. States could intentionally transfer nuclear weapons, or the fissile material required to build them, to terrorist groups. There are good reasons why a state might be reluctant to transfer nuclear weapons to terrorists, but, as nuclear weapons spread, the probability that a leader might someday purposely arm a terrorist group increases. Some fear, for example, that Iran, with its close ties to Hamas and Hizballah, might be at a heightened risk of transferring nuclear weapons to terrorists. Moreover, even if no state would ever intentionally transfer nuclear capabilities to terrorists, a new nuclear state, with underdeveloped security procedures, might be vulnerable to theft, allowing terrorist groups or corrupt or ideologically-motivated insiders to transfer dangerous material to terrorists. There is evidence, for example, that representatives from Pakistan’s atomic energy establishment met with Al-Qa’eda members to discuss a possible nuclear deal.59 Finally, a nuclear-armed state could collapse, resulting in a breakdown of law and order and a loose nukes problem. US officials are currently very concerned about what would happen to Pakistan’s nuclear weapons if the government were to fall. As nuclear weapons spread, this problem is only further amplified. Iran is a country with a history of revolutions and a government with a tenuous hold on power. The regime change that Washington has long dreamed about in Tehran could actually become a nightmare if a nuclear-armed Iran suffered a breakdown in authority, forcing us to worry about the fate of Iran’s nuclear arsenal. Regional Instability The spread of nuclear weapons also emboldens nuclear powers, contributing to regional instability. States that lack nuclear weapons need to fear direct military attack from other states, but states with nuclear weapons can be confident that they can deter an intentional military attack, giving them an incentive to be more aggressive in the conduct of their foreign policy. In this way, nuclear weapons provide a shield under which states can feel free to engage in lower-level aggression. Indeed, international relations theories about the ‘stability-instability paradox’ maintain that stability at the nuclear level contributes to conventional instability.60 Historically, we have seen that the spread of nuclear weapons has emboldened their possessors and contributed to regional instability. Recent scholarly analyses have demonstrated that, after controlling for other relevant factors, nuclear-weapon states are more likely to engage in conflict than nonnuclear-weapon states and that this aggressiveness is more pronounced in new nuclear states that have less experience with nuclear diplomacy.61 Similarly, research on internal decision-making in Pakistan reveals that Pakistani foreign policymakers may have been emboldened by the acquisition of nuclear weapons, which encouraged them to initiate militarized disputes against India.62 Currently, Iran restrains its foreign policy because it fears major military retaliation from the United States or Israel, but with nuclear weapons it could feel free to push harder. A nuclear-armed Iran would likely step up support to terrorist and proxy groups and engage in more aggressive coercive diplomacy. With a nuclear-armed Iran increasingly throwing its weight around in the region, we could witness an even more crisis prone Middle East. And in a poly-nuclear Middle East with Israel, Iran, and, in the future, possibly other states, armed with nuclear weapons, any one of those crises could result in a catastrophic nuclear exchange.

#### Any nuclear war causes extinction – ice age and famine.

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A war fought with 21st century strategic nuclear weapons would be more than just a great catastrophe in human history. If we allow it to happen, such a war would be a mass extinction event that [ends human history](https://ratical.org/radiation/NuclearExtinction/StarrNuclearWinterOct09.pdf). There is a profound difference between extinction and “an unprecedented disaster,” or even “the end of civilization,” because even after such an immense catastrophe, human life would go on. But extinction, by definition, is an event of utter finality, and a nuclear war that could cause human extinction should really be considered as the ultimate criminal act. It certainly would be the crime to end all crimes. The world’s leading climatologists now tell us that nuclear war threatens our continued existence as a species. Their studies predict that a large nuclear war, especially one fought with strategic nuclear weapons, would create [a post-war environment in which for many years it would be too cold and dark to even grow food](http://climate.envsci.rutgers.edu/pdf/RobockToonSAD.pdf). Their findings make it clear that not only humans, but most large animals and many other forms of complex life would likely vanish forever in a nuclear darkness of our own making. The environmental consequences of nuclear war would attack the ecological support systems of life at every level. Radioactive fallout, produced not only by nuclear bombs, but also by the destruction of nuclear power plants and their spent fuel pools, would poison the biosphere. Millions of tons of smoke would act to [destroy Earth’s protective ozone layer](https://www2.ucar.edu/atmosnews/just-published/3995/nuclear-war-and-ultraviolet-radiation) and block most sunlight from reaching Earth’s surface, creating Ice Age weather conditions that would last for decades. Yet the political and military leaders who control nuclear weapons strictly avoid any direct public discussion of the consequences of nuclear war. They do so by arguing that nuclear weapons are not intended to be used, but only to deter. Remarkably, the leaders of the Nuclear Weapon States have chosen to ignore the authoritative, long-standing scientific research done by the climatologists, research that predicts virtually any nuclear war, fought with even a fraction of the operational and deployed nuclear arsenals, will leave the Earth essentially uninhabitable.

### 1AC: Framing

#### The standard is maximizing expected wellbeing.

#### Prefer:

#### 1] Pleasure and pain *are* intrinsic value and disvalue – everything else *regresses* – robust neuroscience.

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**Pleasure** is not only one of the three primary reward functions but it also **defines reward.** As homeostasis explains the functions of only a limited number of rewards, the principal reason why particular stimuli, objects, events, situations, and activities are rewarding may be due to pleasure. This applies first of all to sex and to the primary homeostatic rewards of food and liquid and extends to money, taste, beauty, social encounters and nonmaterial, internally set, and intrinsic rewards. Pleasure, as the primary effect of rewards, drives the prime reward functions of learning, approach behavior, and decision making and provides the **basis for hedonic theories** of reward function. We are attracted by most rewards and exert intense efforts to obtain them, just because they are enjoyable [10].

Pleasure is a passive reaction that derives from the experience or prediction of reward and may lead to a long-lasting state of happiness. The word happiness is difficult to define. In fact, just obtaining physical pleasure may not be enough. One key to happiness involves a network of good friends. However, it is not obvious how the higher forms of satisfaction and pleasure are related to an ice cream cone, or to your team winning a sporting event. Recent multidisciplinary research, using both humans and detailed invasive brain analysis of animals has discovered some critical ways that the brain processes pleasure [14].

Pleasure as a hallmark of reward is sufficient for defining a reward, but it may not be necessary. A reward may generate positive learning and approach behavior simply because it contains substances that are essential for body function. When we are hungry, we may eat bad and unpleasant meals. A monkey who receives hundreds of small drops of water every morning in the laboratory is unlikely to feel a rush of pleasure every time it gets the 0.1 ml. Nevertheless, with these precautions in mind, we may define any stimulus, object, event, activity, or situation that has the potential to produce pleasure as a reward. In the context of reward deficiency or for disorders of addiction, homeostasis pursues pharmacological treatments: drugs to treat drug addiction, obesity, and other compulsive behaviors. The theory of allostasis suggests broader approaches - such as re-expanding the range of possible pleasures and providing opportunities to expend effort in their pursuit. [15]. It is noteworthy, the first animal studies eliciting approach behavior by electrical brain stimulation interpreted their findings as a discovery of the brain’s pleasure centers [16] which were later partly associated with midbrain dopamine neurons [17–19] despite the notorious difficulties of identifying emotions in animals.

Evolutionary theories of pleasure: The love connection BO:D

Charles Darwin and other biological scientists that have examined the biological evolution and its basic principles found various mechanisms that steer behavior and biological development. Besides their theory on natural selection, it was particularly the sexual selection process that gained significance in the latter context over the last century, especially when it comes to the question of what makes us “what we are,” i.e., human. However, the capacity to sexually select and evolve is not at all a human accomplishment alone or a sign of our uniqueness; yet, we humans, as it seems, are ingenious in fooling ourselves and others–when we are in love or desperately search for it.

It is well established that modern biological theory conjectures that **organisms are** the **result of evolutionary competition.** In fact, Richard Dawkins stresses gene survival and propagation as the basic mechanism of life [20]. Only genes that lead to the fittest phenotype will make it. It is noteworthy that the phenotype is selected based on behavior that maximizes gene propagation. To do so, the phenotype must survive and generate offspring, and be better at it than its competitors. Thus, the ultimate, distal function of rewards is to increase evolutionary fitness by ensuring the survival of the organism and reproduction. It is agreed that learning, approach, economic decisions, and positive emotions are the proximal functions through which phenotypes obtain other necessary nutrients for survival, mating, and care for offspring.

Behavioral reward functions have evolved to help individuals to survive and propagate their genes. Apparently, people need to live well and long enough to reproduce. Most would agree that homo-sapiens do so by ingesting the substances that make their bodies function properly. For this reason, foods and drinks are rewards. Additional rewards, including those used for economic exchanges, ensure sufficient palatable food and drink supply. Mating and gene propagation is supported by powerful sexual attraction. Additional properties, like body form, augment the chance to mate and nourish and defend offspring and are therefore also rewards. Care for offspring until they can reproduce themselves helps gene propagation and is rewarding; otherwise, many believe mating is useless. According to David E Comings, as any small edge will ultimately result in evolutionary advantage [21], additional reward mechanisms like novelty seeking and exploration widen the spectrum of available rewards and thus enhance the chance for survival, reproduction, and ultimate gene propagation. These functions may help us to obtain the benefits of distant rewards that are determined by our own interests and not immediately available in the environment. Thus the distal reward function in gene propagation and evolutionary fitness defines the proximal reward functions that we see in everyday behavior. That is why foods, drinks, mates, and offspring are rewarding.

There have been theories linking pleasure as a required component of health benefits salutogenesis, (salugenesis). In essence, under these terms, pleasure is described as a state or feeling of happiness and satisfaction resulting from an experience that one enjoys. Regarding pleasure, it is a double-edged sword, on the one hand, it promotes positive feelings (like mindfulness) and even better cognition, possibly through the release of dopamine [22]. But on the other hand, pleasure simultaneously encourages addiction and other negative behaviors, i.e., motivational toxicity. It is a complex neurobiological phenomenon, relying on reward circuitry or limbic activity. It is important to realize that through the “Brain Reward Cascade” (BRC) endorphin and endogenous morphinergic mechanisms may play a role [23]. While natural rewards are essential for survival and appetitive motivation leading to beneficial biological behaviors like eating, sex, and reproduction, crucial social interactions seem to further facilitate the positive effects exerted by pleasurable experiences. Indeed, experimentation with addictive drugs is capable of directly acting on reward pathways and causing deterioration of these systems promoting hypodopaminergia [24]. Most would agree that pleasurable activities can stimulate personal growth and may help to induce healthy behavioral changes, including stress management [25]. The work of Esch and Stefano [26] concerning the link between compassion and love implicate the brain reward system, and pleasure induction suggests that social contact in general, i.e., love, attachment, and compassion, can be highly effective in stress reduction, survival, and overall health.

Understanding the role of neurotransmission and pleasurable states both positive and negative have been adequately studied over many decades [26–37], but comparative anatomical and neurobiological function between animals and homo sapiens appear to be required and seem to be in an infancy stage.

Finding happiness is different between apes and humans

As stated earlier in this expert opinion one key to happiness involves a network of good friends [38]. However, it is not entirely clear exactly how the higher forms of satisfaction and pleasure are related to a sugar rush, winning a sports event or even sky diving, all of which augment dopamine release at the reward brain site. Recent multidisciplinary research, using both humans and detailed invasive brain analysis of animals has discovered some critical ways that the brain processes pleasure.

Remarkably, there are pathways for ordinary liking and pleasure, which are limited in scope as described above in this commentary. However, there are **many brain regions**, often termed hot and cold spots, that significantly **modulate** (increase or decrease) our **pleasure or** even produce **the opposite**

of pleasure— that is disgust and fear [39]. One specific region of the nucleus accumbens is organized like a computer keyboard, with particular stimulus triggers in rows— producing an increase and decrease of pleasure and disgust. Moreover, the cortex has unique roles in the cognitive evaluation of our feelings of pleasure [40]. Importantly, the interplay of these multiple triggers and the higher brain centers in the prefrontal cortex are very intricate and are just being uncovered.

Desire and reward centers

It is surprising that many different sources of pleasure activate the same circuits between the mesocorticolimbic regions (Figure 1). Reward and desire are two aspects pleasure induction and have a very widespread, large circuit. Some part of this circuit distinguishes between desire and dread. The so-called pleasure circuitry called “REWARD” involves a well-known dopamine pathway in the mesolimbic system that can influence both pleasure and motivation.

In simplest terms, the well-established mesolimbic system is a dopamine circuit for reward. It starts in the ventral tegmental area (VTA) of the midbrain and travels to the nucleus accumbens (Figure 2). It is the cornerstone target to all addictions. The VTA is encompassed with neurons using glutamate, GABA, and dopamine. The nucleus accumbens (NAc) is located within the ventral striatum and is divided into two sub-regions—the motor and limbic regions associated with its core and shell, respectively. The NAc has spiny neurons that receive dopamine from the VTA and glutamate (a dopamine driver) from the hippocampus, amygdala and medial prefrontal cortex. Subsequently, the NAc projects GABA signals to an area termed the ventral pallidum (VP). The region is a relay station in the limbic loop of the basal ganglia, critical for motivation, behavior, emotions and the “Feel Good” response. This defined system of the brain is involved in all addictions –substance, and non –substance related. In 1995, our laboratory coined the term “Reward Deficiency Syndrome” (RDS) to describe genetic and epigenetic induced hypodopaminergia in the “Brain Reward Cascade” that contribute to addiction and compulsive behaviors [3,6,41].

Furthermore, ordinary “liking” of something, or pure pleasure, is represented by small regions mainly in the limbic system (old reptilian part of the brain). These may be part of larger neural circuits. In Latin, hedus is the term for “sweet”; and in Greek, hodone is the term for “pleasure.” Thus, the word Hedonic is now referring to various subcomponents of pleasure: some associated with purely sensory and others with more complex emotions involving morals, aesthetics, and social interactions. The capacity to have pleasure is part of being healthy and may even extend life, especially if linked to optimism as a dopaminergic response [42].

Psychiatric illness often includes symptoms of an abnormal inability to experience pleasure, referred to as anhedonia. A negative feeling state is called dysphoria, which can consist of many emotions such as pain, depression, anxiety, fear, and disgust. Previously many scientists used animal research to uncover the complex mechanisms of pleasure, liking, motivation and even emotions like panic and fear, as discussed above [43]. However, as a significant amount of related research about the specific brain regions of pleasure/reward circuitry has been derived from invasive studies of animals, these cannot be directly compared with subjective states experienced by humans.

In an attempt to resolve the controversy regarding the causal contributions of mesolimbic dopamine systems to reward, we have previously evaluated the three-main competing explanatory categories: “liking,” “learning,” and “wanting” [3]. That is, dopamine may mediate (a) liking: the hedonic impact of reward, (b) learning: learned predictions about rewarding effects, or (c) wanting: the pursuit of rewards by attributing incentive salience to reward-related stimuli [44]. We have evaluated these hypotheses, especially as they relate to the RDS, and we find that the incentive salience or “wanting” hypothesis of dopaminergic functioning is supported by a majority of the scientific evidence. Various neuroimaging studies have shown that anticipated behaviors such as sex and gaming, delicious foods and drugs of abuse all affect brain regions associated with reward networks, and may not be unidirectional. Drugs of abuse enhance dopamine signaling which sensitizes mesolimbic brain mechanisms that apparently evolved explicitly to attribute incentive salience to various rewards [45].

Addictive substances are voluntarily self-administered, and they enhance (directly or indirectly) dopaminergic synaptic function in the NAc. This activation of the brain reward networks (producing the ecstatic “high” that users seek). Although these circuits were initially thought to encode a set point of hedonic tone, it is now being considered to be far more complicated in function, also encoding attention, reward expectancy, disconfirmation of reward expectancy, and incentive motivation [46]. The argument about addiction as a disease may be confused with a predisposition to substance and nonsubstance rewards relative to the extreme effect of drugs of abuse on brain neurochemistry. The former sets up an individual to be at high risk through both genetic polymorphisms in reward genes as well as harmful epigenetic insult. Some Psychologists, even with all the data, still infer that addiction is not a disease [47]. Elevated stress levels, together with polymorphisms (genetic variations) of various dopaminergic genes and the genes related to other neurotransmitters (and their genetic variants), and may have an additive effect on vulnerability to various addictions [48]. In this regard, Vanyukov, et al. [48] suggested based on review that whereas the gateway hypothesis does not specify mechanistic connections between “stages,” and does not extend to the risks for addictions the concept of common liability to addictions may be more parsimonious. The latter theory is grounded in genetic theory and supported by data identifying common sources of variation in the risk for specific addictions (e.g., RDS). This commonality has identifiable neurobiological substrate and plausible evolutionary explanations.

Over many years the controversy of dopamine involvement in especially “pleasure” has led to confusion concerning separating motivation from actual pleasure (wanting versus liking) [49]. We take the position that animal studies cannot provide real clinical information as described by self-reports in humans. As mentioned earlier and in the abstract, on November 23rd, 2017, evidence for our concerns was discovered [50]

In essence, although nonhuman primate brains are similar to our own, the disparity between other primates and those of human cognitive abilities tells us that surface similarity is not the whole story. Sousa et al. [50] small case found various differentially expressed genes, to associate with pleasure related systems. Furthermore, the dopaminergic interneurons located in the human neocortex were absent from the neocortex of nonhuman African apes. Such differences in neuronal transcriptional programs may underlie a variety of neurodevelopmental disorders.

In simpler terms, the system controls the production of dopamine, a chemical messenger that plays a significant role in pleasure and rewards. The senior author, Dr. Nenad Sestan from Yale, stated: “Humans have evolved a dopamine system that is different than the one in chimpanzees.” This may explain why the behavior of humans is so unique from that of non-human primates, even though our brains are so surprisingly similar, Sestan said: “It might also shed light on why people are vulnerable to mental disorders such as autism (possibly even addiction).” Remarkably, this research finding emerged from an extensive, multicenter collaboration to compare the brains across several species. These researchers examined 247 specimens of neural tissue from six humans, five chimpanzees, and five macaque monkeys. Moreover, these investigators analyzed which genes were turned on or off in 16 regions of the brain. While the differences among species were subtle, **there was** a **remarkable contrast in** the **neocortices**, specifically in an area of the brain that is much more developed in humans than in chimpanzees. In fact, these researchers found that a gene called tyrosine hydroxylase (TH) for the enzyme, responsible for the production of dopamine, was expressed in the neocortex of humans, but not chimpanzees. As discussed earlier, dopamine is best known for its essential role within the brain’s reward system; the very system that responds to everything from sex, to gambling, to food, and to addictive drugs. However, dopamine also assists in regulating emotional responses, memory, and movement. Notably, abnormal dopamine levels have been linked to disorders including Parkinson’s, schizophrenia and spectrum disorders such as autism and addiction or RDS.

Nora Volkow, the director of NIDA, pointed out that one alluring possibility is that the neurotransmitter dopamine plays a substantial role in humans’ ability to pursue various rewards that are perhaps months or even years away in the future. This same idea has been suggested by Dr. Robert Sapolsky, a professor of biology and neurology at Stanford University. Dr. Sapolsky cited evidence that dopamine levels rise dramatically in humans when we anticipate potential rewards that are uncertain and even far off in our futures, such as retirement or even the possible alterlife. This may explain what often motivates people to work for things that have no apparent short-term benefit [51]. In similar work, Volkow and Bale [52] proposed a model in which dopamine can favor NOW processes through phasic signaling in reward circuits or LATER processes through tonic signaling in control circuits. Specifically, they suggest that through its modulation of the orbitofrontal cortex, which processes salience attribution, dopamine also enables shilting from NOW to LATER, while its modulation of the insula, which processes interoceptive information, influences the probability of selecting NOW versus LATER actions based on an individual’s physiological state. This hypothesis further supports the concept that disruptions along these circuits contribute to diverse pathologies, including obesity and addiction or RDS.