Space Policy 30 (2014) 215–222

Contents lists available at ScienceDirect

Space Policy

journal homepage: www.elsevier.com/locate/spacepol

Extraterrestrial environmental impact assessments — A foreseeable prerequisite for wise decisions regarding outer space exploration, research and development

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ARTICLE INFO

Article history:
Received 31 December 2013
Received in revised form
14 July 2014
Accepted 24 July 2014
Available online 22 September 2014

Keywords:
Environmental Policy
National Environmental Policy Act
Outer Space Treaty
Moon Agreement
Environmental assessment
Environmental Impact Statement
Space Policy
Futures studies
Extraterrestrial environmental impact

ABSTRACT

Although existing international instruments such as the Outer Space Treaty and Moon Agreement generally express sentiments for minimizing missions' extraterrestrial environmental impacts, they tend to be limited in scope, vague and generally unenforceable. There is no formal structure for assessing how and to what extent we affect those environments, no opportunity for public participation, no uniform protocol for documenting and registering the effects of our actions and no requirement to mitigate adverse impacts or take them into consideration in the decision-making process. Except for precautions limiting forward biological contamination and issues related to Earth satellites, environmental impact analysis, when done at all, remains focused on how missions affect the Earth and near-Earth environments, not how our actions affect the Moon, Mars, Europa, comets and other potential destinations. Extraterrestrial environmental impacts are potentially counterproductive to future space exploration, exploitation and scientific investigations. Clear, consistent and effective international protocols guiding a process for assessing such impacts are warranted. While instruments such as the US National Environmental Policy Act provide legally tested and efficient regulatory models that can guide impact assessment here on Earth, statutory legal frameworks may not work as well in the international environment of outer space. A proposal for industry-driven standards and an environmental code of conduct based, in part, on best management practices are offered for consideration.

1. The need for an environmental review process for actions in outer space

In the US, the two decades following World War II witnessed significant increases in industrial, transportation and agricultural infrastructure development. These supported an expanding industrial society that helped to sustain the increasing population of the nation and world. The associated externalities of wasteful resource depletion, pollution and adverse landscape and ecosystem alteration, however, were often either largely unrecognized or ignored by related industries, the general public and federal and state governments. Public and government awareness of the adverse environmental effects of largely unregulated actions began to change significantly in the 1960s and early 1970s [[1] p. 120]. Rachel Carson's 1962 *Silent Spring* was a significant marker in a process of public recognition of the cumulative adverse impacts of pesticide pollution and the potential for unanticipated, synergistic effects [2]. In 1968, Paul Ehrlich's *Population Bomb* and Garrett Hardin's landmark paper in *Science*, "The Tragedy of the Commons," warned of the dangers of overpopulation and related exploitation of commons' resources without mitigating or otherwise compensating for pollution and physical and biological degradation of the environment [3,4]. The 1969 oil spill in Santa Barbara, California, the largest such spill to that date in the US, coupled with nationwide press reporting of Ohio's Cuyahoga River catching on fire due to petroleum pollution that same year, brought additional attention. The American public was learning of the potential environmental harm that human actions could cause; environmental degradation was becoming a significant social and political issue that affected not only then-current activities but long-range health, agricultural, industrial and infrastructure planning. The US National Environmental Policy Act of 1969 (NEPA) helped to address those concerns and many other nations have enacted similar regulations [5].

We are now rapidly entering an entirely new phase of human environmental impact that likely was not imagined when NEPA was signed into law — the exploration and exploitation of

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http://dx.doi.org/10.1016/j.spacepol.2014.07.001
0265-9646/

environments beyond Earth's atmosphere. As nations and private enterprises increasingly describe their intentions to undertake major actions on planets, moons, asteroids and even comets, it is sobering to consider that there is no comprehensive process required by the US, other states or groups of states, or the UN for assessing human impacts on those extraterrestrial environments. Rather, the focus has been on reducing forward biological contamination and the dangers and liabilities inherent in objects launched with the intent that they will return to Earth or orbit Earth, not for missions that land on other celestial bodies, such as Mars. Belgium's Law on the Activities of Launching, Flight Operation or Guidance of Space Objects is an exception that anticipates the need for consideration of extraterrestrial impacts [6]. It states at Article 2 §1, "This law covers the activities of launching, flight operations and guidance of space objects carried out by natural or legal persons in the zones placed under the jurisdiction or control of the Belgian State or using installations, personal or real property, owned by the Belgian State or which are under its jurisdiction or its control." Article 3(1) defines "space object" as "any object launched or intended to be launched, on an orbital trajectory around the Earth or to a destination beyond the earth orbit." The law requires that an environmental impact assessment be submitted prior to the launch, assessing the effects of the action on both the Earth and any celestial body affected. It is attached to the application for authorization by the Belgian Minister for Space Policy, who may add special conditions regarding extraterrestrial environments. Additional assessments may be required during and after the mission. These requirements reflect the sentiments of the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (Moon Agreement), to which Belgium is an official party [7]. However, Belgian space law's authorization and supervision regime only applies to non-governmental entities launching from areas under the jurisdiction or control of the Belgian state, not to actions of the Belgian government itself or to launches from areas outside of Belgian jurisdiction. To date, actions approved under the law have been confined to near-Earth launch and return and satellite missions, not to any actions affecting celestial bodies or other environments beyond Earth orbit.

Article IV of the 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (the Outer Space Treaty) places limitations on the testing and use of weapons on extraterrestrial landscapes [7]. This has indirect environmental protection value in that if there are no explosions due to nuclear weaponry there will be no resulting environmental damage. But adverse impacts due to other foreseeable human actions are generally not addressed by any state or by international agreement or treaty except for Belgium as noted above [[8] p. 58]. Except for impacts in the immediate vicinity of assembly and launch facilities, downrange areas where hardware may fall and various re-entry scenarios, space activities are often falsely assumed to be benign with respect to environmental impacts [[9] p. 238]. But this conclusion has been reached only because the focus has been on Earth, not on extraterrestrial sites. For example, the US National Aeronautics and Space Administration's (NASA) 2005 *Final Programmatic Environmental Impact Statement for the Mars Exploration Program* contains detailed discussions and analyses of the Program's environmental and other effects on Earth (such as air quality near the launch pad and impact on the economies of nearby communities), but there is no mention of potential impacts to Mars [10]. Likewise, the 2006 *Final Environmental Impact Statement for the Mars Science Laboratory Mission* includes Cape Canaveral, Florida, and other locations on Earth including the troposphere and stratosphere in its consideration of impacts, but does not address the impact of the Mars rover Curiosity on Mars itself [11].

As expressed by NASA and the European Space Agency (ESA), the search for existing or extinct extraterrestrial life is a priority among their programs [12–14]. The identification of a sea of oxygen-rich water under the ice of Jupiter's moon Europa and oxygen and water ice on Saturn's Enceladus have heightened interest in exploration and exploitation there [15]. The probability of discovering past or present extraterrestrial life in our Solar System is no longer remote, and if the area is expanded to include our galaxy, it may be more a matter of when rather than if [16,17]. Forward biological contamination, defined as the intentional or unintentional introduction of Earth-origin life (mostly microorganisms and similar forms such as bacteria and spores) to any extraterrestrial venue, is of special concern. Precautions are clearly expressed in the Preamble to the Planetary Protection Policy of the Committee on Space Research [18,19]. Any such contamination may confound our search for extraterrestrial life as well as potentially disrupt the alien living systems we may be attempting to document and research. Yet standards and protocols may not be uniform and enforcement can be lax, as evidenced in the pre-launch contamination of the Mars Science Laboratory [20].

Similar to the emergence of American environmental awareness in the early 1960s, some are beginning to recognize the potential for human actions to adversely affect extraterrestrial environments. However, others either do not foresee adverse impacts as being problematic or maintain that environmental regulation would be overly restrictive and counter to the spirit and purposes of space exploitation. As the resources of the New World likely first appeared limitless to European explorers, so bountiful that the traditions of conservation and husbandry practiced at "home" seemed irrelevant, so might our Solar System seem so vast that our impacts would appear inconsequential. But we must guard against repeating in outer space our past mistakes of underestimating the cumulative, enduring and potentially synergistic environmental effects of our actions here on Earth.

2. The increasing scope of extraterrestrial actions

The crewed US Apollo 11 Mission in 1969 and the five subsequent Apollo missions that landed on the Moon through 1972 left little more than an iconic footprint, golf ball and flag in addition to several tons of miscellaneous hardware on the surface. There was no intrusive mining, surface alteration or other landscape-altering action other than the collection of surface rocks. The Moon's surface has not likely been significantly affected; debris is confined to the surface layer and locations of larger pieces have been cataloged and mapped. On Mars, as with the Moon, disturbances have been relatively minor. Missions with greater physical impact have included Deep Impact, which fired a projectile into comet Tempel 1 in 2005, blasting a crater and causing the ejection of a plume of comet components into space that provided data on its composition. But the number of such missions and the impacts they may impart to the Moon, Mars and elsewhere are increasing. If the current paucity of assessment and reporting continues, it may become unmanageable to catalog debris, landscape alteration, the location, nature and concentration of pollutants (such as lubricants, hydraulic fluids, metals and other materials with the potential to enter the environment) and other environmental impacts.

During the latter decades of the 20th century, the US and the USSR/Russia were the only entities sponsoring ambitious space programs, but the field has now grown to include other nations and private commercial enterprises. For example, the Indian Space Research Organization (ISRO) has launched 71 satellites, including high altitude geosynchronous Earth satellites and the Mars Orbiter Mission, a Mars satellite that will remotely survey the planet's surface and atmosphere, as well as test engineering systems for