



Convergence between the study of ecosystem services and nuclear technology – a necessary approach

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ABSTRACT

If in the 19th century scientific knowledge moved from a generalist perspective to a growing specialization, in recent decades, problems that transcend disciplinary and political boundaries have required solutions based on interdisciplinary research and global actions, which led to the establishment of the Sustainable Development Goals (SDGs). Viewing from the latter perspective, the study of ecosystem services has converged on a fast-growing, transdisciplinary area of knowledge, at the same time that the advances in the nuclear field have enabled applications in industry, health, agriculture and the environment. Considering the development of these two areas of knowledge, the objective of this study is to evaluate the correlation between Ecosystem Services (ES) and Nuclear Science and Technology (NST), by means of category building and content analysis applied to articles compiled from Web of Science. From 1980 to June 2020, 27,301 records (articles and reviews) were listed for the term “Ecosystem Service*”. When refining the result with the application of descriptors related to the nuclear field, correspondences were found for “Uranium”=14; “Nuclear Power”=6; “Nuclear Energy”=3; “Nuclear Technology*”=1; “Nuclear Fuel*”=1; “Nuclear Material*”=1; “Radiation”=7; “Isotope*”=188, totalizing 221 correspondences. On the other hand, 9,949 records were obtained for the same time interval, when using the descriptors for the nuclear field, plus the terms “Nature” or “Ecosystem*” or “Environment”. Despite attesting that NST truly converges on ES, this correlation needs to be made more explicit in ES studies, in order to expand the perspectives for the conservation, preservation and recovery of the ecosystem services and their contribution to human well-being.

Keywords: Nuclear Science, Sustainable Development Goals, Human well-being.

1. INTRODUCTION

Ecosystems are defined as dynamic complexes composed of plant, animal, micro-organism and inorganic (water, soil and air) communities that interact as functional units [1, 2], whereas ecosystem services (ES) are understood to be the ecological characteristics, functions or processes that contribute directly or indirectly to human well-being (HWB), i.e. they are the benefits that people obtain from ecosystems [2 – 4].

The study of ES emerged in the 1980s and is now consolidated as a well-defined transdisciplinary area [4 – 6], with journals that deal specifically with the subject. Established in 2012, ECOSYSTEM SERVICES stands out as an international, interdisciplinary journal that deals with the science, policy and practice of ES. From 2012 to June 2020, ECOSYSTEM SERVICES published 1.057 articles [7].

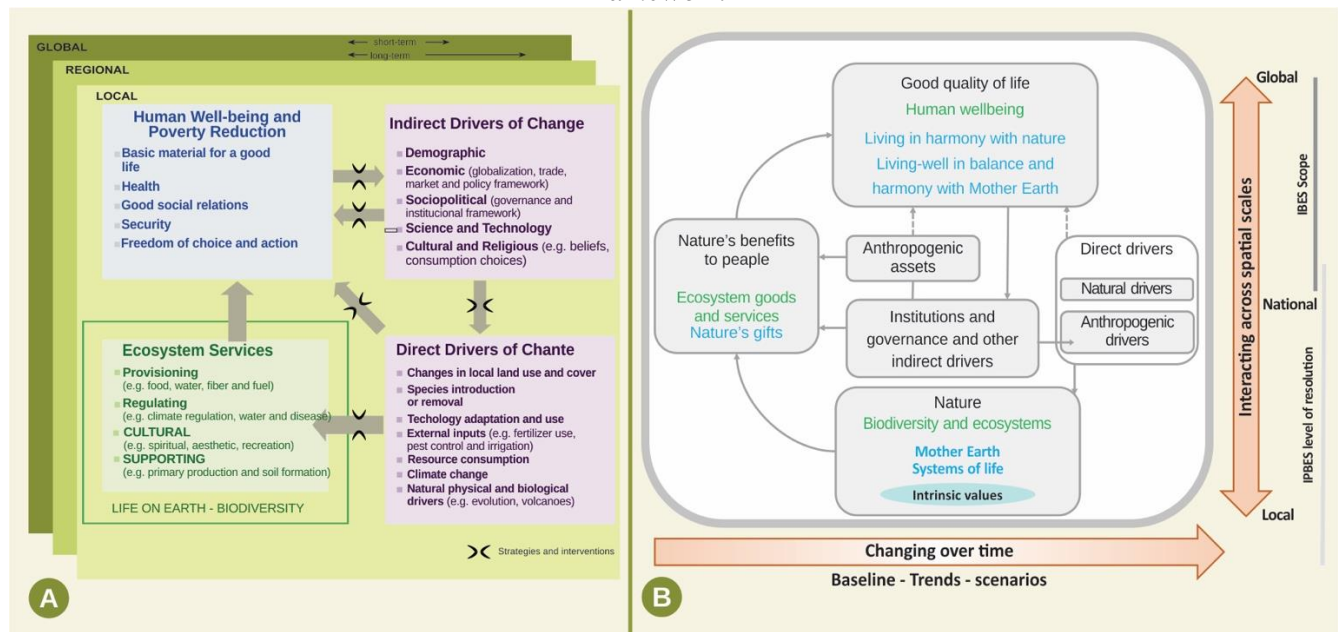
Both the concept of ES and its applications have been widely popularized since the Millennium Ecosystem Assessment – MA took place from 2001 to 2005. It is considered the largest scientific task force ever undertaken to evaluate the consequences of ecosystem changes for ~~human well-being~~ HWB and the scientific basis for action [2, 6, 8 – 10]. MA concluded that more than 60% of ES are being degraded or transformed, putting HWB at risk [8].

Currently, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services – IPBES, established in 2012, is the largest global effort to develop a synthesis of ES and knowledge on biodiversity [11]. For IPBES, ES were redefined as “nature’s contributions to people – NCPs”, in other words, NCPs would be a more inclusive and diverse interpretation of human-nature relations [11 – 14] and ES a subset of NCPs [15]. Although it is too early to evaluate the effectiveness and acceptance of the redefinition proposed by IPBES, for researchers and decision-makers [4, 16, 17], the concept in its pluralism embraces a range of perspectives and connects ecologists, economists and social scientists [Figure 1]. Despite the debates regarding conceptual frameworks, evaluation methodologies, valuation and main terminology [15, 19], the concept of ES is considered operational [17]. However, its scope was not sufficient to establish a connection with nuclear scientists working in the environmental field, the object of this study.

The concepts related to ES are useful ways of highlighting, measuring and valuing the degree of interdependence between human beings and nature, providing tools that communicate with different audiences, in order to achieve different purposes in the fields of science and public policies. In

addition, the loss of these services affects both well-being and development in their multiple dimensions. The promotion of well-being and the protection of the environment are the most urgent global challenges and appear in the central ideas of the Sustainable Development Goals (SDGs).

Figure 1: Millennium Ecosystem Assessment Conceptual Framework and IPBES Conceptual Framework



Note: a. Millennium Ecosystem Assessment Conceptual Framework [2, 8]. b. The Platform's conceptual framework has been designed to build shared understanding across disciplines, knowledge systems and stakeholders of the interplay between biodiversity and ecosystem drivers, and of the role they play in building a good quality of life through nature's contributions to people [11, 13].

Adopted in 2015 by the 193 United Nations' member-states as part of the 2030 Agenda, the 17 SDGs, with their 169 targets and 244 associated indicators, were established as a new international set of action plans to address the challenges of sustainable development [20 – 22]. The SDGs are action plans established to guide government and society in finding solutions to current problems in a sustainable manner, including the challenges related to poverty, inequality, environmental degradation, prosperity, climate, peace and justice [22, 23]. Ecosystem services uphold all dimensions of HWB, and their integration into established strategies to achieve SDGs is crucial [23 – 28].

Global sustainability policies, such as SDGs, aim to ensure sustainable development. For the operationalization of these policies, the concept of ES stands out, whose popularization and

exponential trajectory are attributed to MA [2, 8], as it presented a holistic way to understand and evaluate the human impact on the planet and on the local and regional socio-ecological dynamics [9, 10].

The use and application of Nuclear Science and Technology (NST) are significant to SDGs in many aspects, contributing in areas such as energy, human health, food production, water resource management and environmental protection [29 – 32], especially when it comes to the conservation, evaluation or recovery of ecosystems and their services. Considering the various applications of nuclear technology and the advancement of these two fields of knowledge, the objective of this study is to evaluate the correlation between ES and NST.

2. MATERIALS AND METHODS

The data bank used for the analysis of the themes related to ecosystem services and their relationships with the areas of knowledge on nuclear technologies was exploring the Scopus database [33] and systematically compiling the records from the Web of Science [34]. Scopus and Web of Science provide a large number of peer-reviewed documents at different subscription levels. Access granted to academics of the University of Brasília (UnB) allowed the selection of documents corresponding to “article” and “review” published from 1980 to June, 2020. Firstly, records with the term “Ecosystem Service” or “Ecosystem Services” as a topic were retrieved, that is, when these terms appeared either in the title, abstract or as keywords. The data collected for the analysis was acquired from Web of Science. From this result, a new search was applied for the descriptors related to the nuclear field, with the application of following masks: “Uranium”; “Nuclear Power”; “Nuclear Energy”; “Nuclear Technology”; “Nuclear Fuel”; “Nuclear Material”; “Irradiation”; “Isotope”; “Nuclear Application”; “Nuclear Physics”; “Nuclear Reactor”; “Nuclear Radiation”; “Nuclear Instrumentation”; “Nuclear Security”, and “Nuclear Research”. Analyses and systematization of the information made available on the site of the International Atomic Energy Agency [29] and in correlated bibliography on the applications of nuclear technologies [30 – 32, 35] were performed to establish the relationships between the two areas of knowledge.

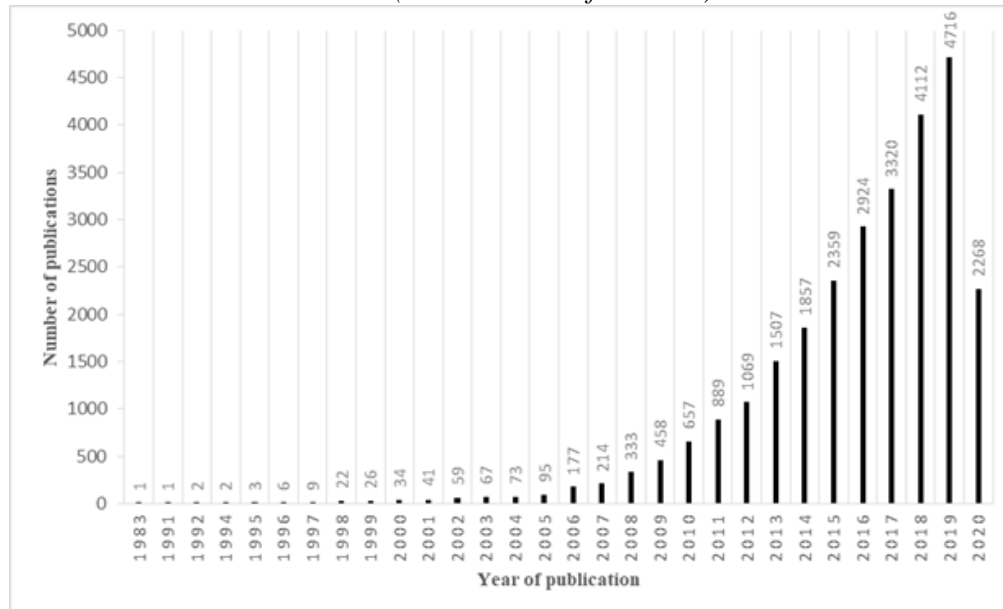
3. RESULTS AND DISCUSSION

3.1. Ecosystem services (ES) and interactions with human well-being (HWB)

The terms “nature’s services” and “ecosystem services” first appeared in the literature respectively in 1977 [36] and 1980s [37]. However, the idea that natural systems provide benefits that support HWB is considered as old as humanity itself [4, 38]. The area of knowledge about SE considers as a framework for its development two seminal publications of 1997 [3, 39] from which the research and political applications of the approach have expanded [4].

In 2017, a survey of the Scopus database resulted in more than 17,000 records published with the term “ecosystem services” in the title, abstract or keywords, with more than 2,800 records in 2016 alone [4]. Within the scope of this study, similar surveys were conducted in June 2020 [33, 34], using the terms “ecosystem service” and “ecosystem services” as search criteria, resulting in 26,294 and 27,301 records (“article” and “review”), respectively from Scopus and from Web of Science. Figure 2 shows the results obtained from Web of Science by year of publication, from 1983 to 2020.

Figure 2: Growth of the area of knowledge ecosystem services, in the period from 1983 to 2020(source: Web of Science).



As mentioned before, ES is a fast-growing area of transdisciplinary knowledge, mainly thanks to the urgency of problems that transcend disciplinary boundaries and that require a broader perspective to understand the complexity of the entire system and the possible solutions [5]. Since MA, the ES

concept has grown in popularity mainly because of the better conditions for environmental decision-making, including multifunctional planning to understand the role of ecosystems in the provision of services and the analysis of how changes in land use and management may restrict future ES supply [10].

Although several ES classifications have been proposed [6] for the operational purposes of this article, we opted for the categorization into functional lines presented by MA [2], that is: provision, regulation, cultural, and support categories. While there is a growing demand for ES, there is also an increasingly dramatic degradation of the capacity of ecosystems to provide them. The very lack of knowledge about the services provided by ecosystems constitutes one of the barriers to the protection of natural heritage. The degradation of ecosystems and the consequent change in their services directly affect HWB, with impacts on safety, on the material goods necessary for a healthy living, on health, and on social and cultural relations. These well-being components influence people's freedom of choice and, at the same time, it is influenced by them [2, 8].

The framework proposed by MA (Figure 1A) [2] conceptualizes the links between drives that directly or indirectly affect ES and biodiversity (such as population, technology, lifestyles); changes in ecosystems and the services they provide affect HWB. Figure 1 shows these links occur between spatial and temporal scales, and actions can be taken to respond to negative changes or to increase positive changes at almost every point. The MA results point to major problems that are associated with the management of ecosystems and that mainly impact the poorest populations. The degradation or unsustainable use of approximately 60% of the services stands out. These declining services involve pure water, capture fishing, air and water purification, local and regional climate regulation, control of natural threats and epidemics [8]. Many services deteriorate as a result of actions taken to intensify the provision of other ES – the so-called trade-offs, whose management involves different objectives, values and stakeholders [2, 8, 41 – 43].

The main large-scale initiatives and projects including ES and natural capital are [4]: Millennium Ecosystem Assessment (MA) [8; 44]; The Economics of Ecosystems and Biodiversity (TEEB) [45; 46]; Ecosystem Services Partnership [47]; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) [11]; EU Biodiversity Strategy to 2020 [48]; Wealth Accounting and Valuation of Ecosystem Services (WAVES) [49]; Natural Capital Project (NatCap)

[50]; Natural Capital Coalition (NCC) [51]; COMMON International Classification of Ecosystem Services (CICES) [52].

Ecosystem Services trade-offs involve a wide and complex range of exchanges related to the use of ecosystems, including land-use change, management regimes, technical versus nature-based solutions, use of natural resources and management of species. Even if the total cost resulting from the loss and deterioration of these services is difficult to measure, the evidence points to substantial and increasing values [8]. In 1997, the services provided by the Earth's ecosystems were estimated, on average, at U\$ 33 trillion/year. For 2011, the estimate was that ES should totalize U\$ 125 trillion/year (assuming updates in the values and areas of the biomes), or U\$ 145 trillion/year (considering the updates in the values of the services). Land-use changes corresponded to ES losses between US\$ 4.3 and US\$ 20.2 trillion/year in the period from 1997 to 2011 [3, 53].

Ecosystem Services have mobilized both the media and companies, including initiatives such as the partnership between Dow Chemical and The Nature Conservancy – TNC to account for the costs of the ecosystem and the benefits of each business decision that will provide a significant addition to ES assessment knowledge and techniques. Similarly, TruCost, a UK-based company, evaluates the impact that publicly owned corporations have on natural capital and Ecosystem Services [4].

3.2. From Ecosystem Services (ES) to Sustainable Development Goals (SDGs): The role of Nuclear Science and Technology (NST)

The safe supply of ES that contribute to HWB is directly related to SDGs. Information on the state of ES and their trends [28] is highly relevant to the fulfillment of the 2030 Agenda [20]. The wide range of themes addressed in SDGs, from reducing poverty and hunger the people, economies and sustainable ecosystems, provides a multisectoral approach, in which the reconstruction and strengthening of the integrity and function of ecosystems are related, to some degree, to all SDGs [24 – 28, 54 – 59]. Biodiversity and ES uphold all dimensions of HWB – social, cultural and economic [2, 8, 11, 53]; however, their unsustainable exploitation compromises the achievement of the SDGs, which necessarily depend on ecosystem management for the protection and sustainable and equitable provision of their services [23, 60]. SDGs relate to each other by means of their indicators, whose

results contribute to the achievement of different goals. The safe supply of ES and their contribution to HWB is the way to achieve the established goals [23].

The least developed countries and regions, and the poorest people who depend directly on access to ecosystems, are the most affected by the degradation of their services, whose constant decrease in capacity contributes to the increase in inequalities and disparities between groups and populations [8], with implications for the level of success of the SDGs, which should differ widely among countries [23, 60]. Due to the severity of the damage to the planet, people's health will be increasingly threatened if urgent measures are not taken, highlighting that the health and prosperity of humanity are directly linked to the conditions of the environment. Out of the 244 SDG monitoring indicators, 93 refer to environmental issues, so much so that the environmental dimension of the 2030 Agenda is configured as an entry point to promote integrated achievements of the SDGs with an impact on the economy and social aspects of sustainable development, and vice-versa [23, 60].

The 17 SDGs of the 2030 Agenda aim to stimulate action in areas of critical importance to humanity and the planet. Nuclear Science and Technology (NST) provides tools to achieve SDGs in areas such as energy, human health, food production, water resource management and environmental protection. The use of these techniques contributes directly to nine of the 17 SDGs [29; 35]. The information on the application of nuclear and isotopic tools to address environmental issues is systematized in the Box 1, with a focus on evaluation, recovery and conservation of ecosystem services, also considering the contribution of the NST to the identified SDGs.

Box 1: Ecosystem services mediated by Nuclear Science and Technology (NST) and contribution to the Sustainable Development Goals (SDGs)

Ecosystem services	NST contributions to SDGs and their relationships with ecosystem services	Goal
Food (crops, livestock, aquaculture, capture fisheries); Genetic resources, Biochemicals, Natural medicines, Pharmaceuticals; Fresh water; Erosion Regulation; Water purification; Pest regulation; Cultural services	Conservation of soil, water and agricultural resources; protection of crops against pests; development of new varieties of plants resistant to diseases and changing climatic conditions; increase in soil salinity; protection of animal health and improvement in animal breeding practices.	SDG 2 Zero hunger

Box 1: Ecosystem services mediated by Nuclear Science and Technology (NST) and contribution to the Sustainable Development Goals (SDGs) (cont.)

Ecosystem services	NST contributions to SDGs and their relationships with ecosystem services	Goal
Water regulation; Erosion regulation; Climate regulation; Fresh water; Water purification and waste treatment; Disease regulation; Capture fisheries; Aquaculture; Cultural services	Studies on: quality and quantity of water resources; adapting to climate change; groundwater flow and route of contaminants. Mapping the size of groundwater resources; detection and analysis of pollutants in water bodies and tracking their movement; destruction of wastewater pollutants; monitoring of critical water bodies; development of water remediation time models under different nitrate input scenarios; study of nutrient load linkages, eutrophication and increasing frequency and intensity of harmful algal blooms in freshwater; identification of the origin (natural or anthropogenic) of increased concentrations of trace elements in groundwater and contamination of surface water exposed to air in open tanks by radionuclides; use of stable trackers and radioisotopes to identify sources of contamination and quantify the transformation and biodegradation of pollutants in aquifers; use of radiation for wastewater treatment.	SDG 6 Clean water and sanitation
Climate regulation; Air quality regulation	Clean, low-carbon energy.	SDG 7 Affordable and clean energy
Freshwater; Climate regulation; Water purification and waste treatment; Air quality regulation	Cleaning of wastewater and air contaminants; monitoring and tracking of construction sediments, dredging or dumping in coastal areas; use of radiation to treat nitrogen oxides (NO _x) and sulfur oxides (SO _x) present in combustion gases (combustion exhaust gases produced in plants), as well as effluents from the textile dye industry and to make sewage sludge suitable for application in agriculture.	SDG 9 Industry, innovation and infrastructure
Freshwater; Climate regulation; Air quality regulation; Biodiversity; Crops; Water regulation; Water purification; Natural hazard regulation	Data collection and monitoring of how climate change affects the environment; identification of polluting sources and GHG emissions; development of crops that reduce emissions and favor CO ₂ capture/retention in the soil and “climate-smart” farming methods – optimization of food production in adverse weather conditions (drought and high temperatures), and for the conservation and preservation of natural resources (such as soil and water); studies of natural processes that influence the global dissemination of pollutants and their deposition rates on land and sea; monitoring of green-house gas (GHG) routes and other pollutants in the atmosphere, their distribution and impacts on ecosystems, in terrestrial and marine environments; development of models to predict changes in the global carbon cycle and the climate.	SDG 13 Climate action

Continua

Box 1: Ecosystem services mediated by Nuclear Science and Technology (NST) and contribution to the Sustainable Development Goals (SDGs) (cont.)

Ecosystem services	NST contributions to SDGs and their relationships with ecosystem services	Goal
Spiritual and religious values; Aesthetic values; Recreation and ecotourism; Climate regulation; Water regulation; Water purification and waste treatment; Genetic resources; Capture fisheries	Tracking and monitoring of contaminants in marine environments, such as microplastics, radionuclides and heavy metals; studies on how contaminants affect marine organisms and ecosystems, seafood quality and contaminant transfer in the food chain; studies on ocean acidification and its consequences on marine life and ecosystems; identification of ways to protect the ocean and coastal communities; radiolabeled tracers for studies of how microplastics are contaminated by organic pollutants and how they transfer such contaminants to marine organisms; study of natural archives (sediment cores, corals and shells) to evaluate contaminant accumulation rates in coastal and marine ecosystems, and historical analysis of pollution incidents in these ecosystems.	SDG 14 Life below water
Spiritual and religious values; Aesthetic values; Crops; Fresh water; Biochemicals, natural medicines, pharmaceuticals; Erosion regulation; Pollination; Genetic resources	Development of efficient methods of soil management, soil conservation and crop production, with the possibility of reversing erosive processes and avoiding degradation of water resources; identification of isotopes in different contaminants (such as chemical fertilizers or industrial pollutants) to measure their concentration and trace their source; restoration of radiation-contaminated areas, including uranium production sites; use of nuclear and isotopic tools to study the impact and movement of pollutants in terrestrial environments and the compromise of ecosystem services.	SDG 15 Life on land

Box 1 shows a set of correlations between SDGs, ES and NSC. The data were obtained from the analysis of official records of the International Atomic Energy Agency, available in the IAEA website and publications [29 – 32, 35]. Both the correlations in the box and those related throughout the study are based on the conceptual framework of the Millennium Ecosystem Assessment, expressed in Figure 1A. From this framework, it is understood that Nuclear Science and Technology, an indirect vector of change in the benefits provided by ecosystems, induce positive alterations in ecosystem services and directly affect human well-being at different scales.

The direct connection between the services provided by ecosystems and the challenges for achieving SDGs considers the dependence that humanity and human development have on ecosystems. This interaction is influenced by factors such as population growth, change in age distribution, distribution of wealth, consumption patterns and displacement (planned and unplanned

migration). The connections established in Box 1 show that this interaction contributes directly to achieving SDGs 2, 6, 7, 9, 13, 14 and 15 (zero hunger; clean water and sanitation; affordable and clean energy; industry, innovation and infrastructure; climate action; life below water; life on land).

Tools based on nuclear science are used to study terrestrial and aquatic systems. Stable isotopes and nuclear techniques are used to assess freshwater resources, biological systems, atmospheric processes and ocean ecosystems, as well as to improve agricultural practices; to assess impacts on the environment, particularly the fingerprint of natural and anthropic pollution and to study the processes in which pollutants become integrated into biological, geological and chemical cycles [29, 32].

Nuclear technologies provide solutions to help tackle hunger and malnutrition and improve environmental sustainability. In India, for example, sheep farming is important for the livelihoods of family farmers and landless people and is one of the main economic activities. As sheep normally produce only one lamb per gestation, a systematic marker breeding program has been developed to increase prolificity in local sheep. Positive results in reproductive efficiency and the rate of twinning in sheep herds benefit smallholder farmers, with additional lambs at each breeding season. In Africa, cassava cultivation using methods improved in nuclear science and related techniques triple productivity. The application of nitrogen isotope analysis allows quantification of the precise amount of fertilizer to be used and at what stage of the plant's life cycle and how to incorporate locally available manure as an additional nutrient. Isotopic techniques are also used to determine the amount of water that cassava needs to develop and minimize waste [29].

Water security, which includes the availability of ecosystem services, their quality, management and protection, is a critical issue for human development, environmental and economic sustainability, and access to water is critical for meeting human needs, for food and energy production, for industry and for environmental protection. Nuclear isotopic techniques provide important information on water sources and the human impact on the climate [29, 32]. Land-based sources account for about 77% to 100% of marine pollutants, including heavy metals, persistent organic pollutants, pathogens, radioactive substances, hydrocarbons, petrochemicals, plastics and other forms of solid waste, heat and noise [35].

Nuclear and isotopic techniques are used to understand and propose mitigation strategies and tools for the environmental impacts of radionuclides, heavy metals, trace elements and organic contaminants, as well as for climate change, habitat destruction and biodiversity loss in the marine

environment, and radiopharmaceutical applications for environmental pollution. Still focusing on the marine environment, pollution assessments are carried out to improve the safety of seafood, and stable isotopic techniques are applied to study pollution processes and sources of fingerprint pollutants [35].

The environmental dimension of sustainability reinforces the vital connection of ecosystems and their services with human society and its development, expressed in its multiple dimensions in the SDGs. Although the studies on ES and NST are correlated, NST contributions are not being incorporated into ecosystem services as an area of knowledge, as shown in Table 1.

Table 1: NST contribution to the development of the ES fields of knowledge.

Keywords	Nuclear Science and Technology Area			Ecosystem Services Area ²	
	Number of records	Refined results using the expression		Refined results; Environmental Sciences ¹	Refined results for key-works in NST area
		“Ecosystem*” and “Nature” or “Water resource*”	“Ecosystem*” or “Nature” or “Environmental”		
“Uranium”	47,732	81	5,665	1,498	14
“Nuclear Power”	23,959	44	2,971	824	6
“Nuclear Energy”	5,600	16	909	205	3
“Nuclear Technology*”	1,019	1	105	14	1
“Nuclear Fuel*”	9,787	5	935	216	1
“Nuclear Material*”	2,493	--	208	39	1
“Irradiation”	364,798	107	19,438	1,971	7
“Isotope*”	207,105	1,092	30,085	5,035	188
“Nuclear Application*”	754	--	51	2	--
“Nuclear Physics*”	5,091	1	254	10	--
“Nuclear Reactor*”	9,961	11	621	100	--
“Nuclear Radiation*”	942	--	67	1	--
“Nuclear Instrumentation*”	128	--	8	--	--
“Nuclear Security”	329	--	27	6	--
“Nuclear Research”	1,726	1	98	19	--
TOTAL OF RECORDS	681,424	1,359	61,442	9,949	221

Source: Prepared based on the search engine available on the Web of Science database, on June 29th, 2020. Note: ¹Records listed in the Web of Science Category “Environmental Sciences” from the refined results for the terms “ecosystem” or “nature” or “environmental”. ²Total number of records with the term “ecosystem service*” = 27,301.

The studies on the application of nuclear technology to environmental issues, mapped in this exploratory research from official records and information of the International Atomic Energy Agency (IAEA) [29 – 32, 35], showed its factual and concrete relevance for the conservation,

recovery and evaluation of ecosystem services. However, the use of nuclear techniques was timidly identified in the studies of ecosystem services – for more than 27 thousand records (articles and reviews, since 1980), there was a correspondence of only 221 studies, which represents 0.80% of the records. On the other hand, by systematizing nuclear publications for the same descriptors and filters (articles and reviews since 1980), more than 780 thousand results were found. In an attempt to approximate, the results for each descriptor were refined with the use of the expressions <“ecosystem*” and “nature” or “water resource*”>; in its entirety, this new research resulted in 1,359 studies. Nuclear-related publications were again systematized to apply the expressions <“ecosystem*” or “nature” or “environmental”>. In this last selection, more than 61 thousand records were located, and 9,949 were published in the “Environmental Sciences” category.

Increased collaboration, both among academic disciplines and between the Academy and the wider society, is fundamental for the development of research and practice of ecosystem services, especially when it is observed that even IPBES, which carries out a great interdisciplinary work effort, has its base dominated by natural scientists [17].

Although this evaluation does not include content analysis of selected records to identify a more precise indicator on those that, in fact, could contribute to the state of the art on ecosystem services, the results presented here are very relevant, especially for indicating gaps in knowledge and integration and cooperation among researchers from different, but correlated areas. These results highlight the relevance of inter- and transdisciplinary research for the development of appropriate processes for the production of knowledge in ES [17].

4. CONCLUSION

The fast-growing ES field is a well-established area of knowledge, with assessments being developed on global and regional scales by various initiatives, institutions and researchers, especially IPBES. In these evaluations, as in the case of the Intergovernmental Panel on Climate Change, no new research is produced, but the available knowledge is systematized, in order to highlight some important issues. In this context, it is possible that this “invisibility” of NST-related studies may leave knowledge gaps in ES assessments or lead to partial results if they are not in fact being considered in the assessments.

As relevant as this hypothesis is the evidence that the field of knowledge on ES disregards important contributions to its development from NST. If, on the one hand, the information made available by IAEA shows clear interfaces of nuclear applications to ES, on the other hand, only 221 records with nuclear-related descriptors were identified amidst about 27 thousand publications on ES. Complementary studies to measure the existing gaps are necessary and urgent. Depending on their size, the incorporation of these “new” studies that were “invisible” can promote a significant advance in a short space of time in the field of ecosystem services, in addition to integrating NST scientists who develop investigations related to ecosystems and their services but who may be on the margins of this research network.

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