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Maritime Trade and Biological Invasions Management: A Seaport Platform of Environmental Surveillance in Cotonou, Benin, as a Pilot Multi-Stakeholder Initiative

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The Seaport Platform of Environmental Surveillance (PPSE, or *Plateforme Portuaire de Surveillance Environnementale* in French) was officially inaugurated in Cotonou Seaport (CS), Benin, by the end of 2021. To our knowledge, this platform is the first laboratory dedicated to the monitoring and management of invasive species to be built inside the walls of an African seaport. Its creation has benefitted from a combination of favorable factors, and its existence has resulted from a long-term, multi-stakeholder and still ongoing process that we here describe and analyze. We believe that the PPSE is an innovative science-guided operational initiative that may be useful to replicate in other settings throughout the world.

Keywords

science society interface, invasive species, transport, science operationalization, Benin

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1. INTRODUCTION

In the context of increasingly visible consequences of global changes, claims for science-guided concrete recommendations towards decision makers and socio-economic stakeholders are multiplying. This requires that science production keeps aligned with societal needs and constraints, and that dialog and interactions between academics and non-academics remain possible and constructive, leading to mutual understanding and, *in fine*, operational collaboration. Though theoretically sound, this is not always straightforward and easy to implement in the real life. We here share what we feel is a successful story where scientific production, societal obligations and socio-economic stakeholders' objectives meet and fuel collaborative action. In essence, we describe and analyze the process that led to the setup of the Seaport Platform of Environmental Surveillance (PPSE, or *Plateforme Portuaire de Surveillance Environnementale* in French) in 2021 in Cotonou, Benin, the first lab device housed within an international seaport, conducted by academics and dedicated to invasive species monitoring and management. The first part of our paper provides a general overview of the background, namely the scientific and regulatory aspects of biological invasions, as well the local context of Cotonou Seaport (CS). The second part focuses on the origin and co-construction process of the PPSE. We then conclude by discussing some of the identified issues that should be addressed to reach autonomy and sustainability.

1.1 Biological invasions

Biological invasion is defined by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) as "a process involving the transport of a native species outside of its natural range, intentionally or unintentionally, by human activities to new regions where it may become established, spread and ultimately adversely impact nature, nature's contributions to people, and good quality of life" (IPBES 2023). Although the voluntary or involuntary introduction of alien species into new environments does not always translate into successful implantation (hence biological invasion), once installed, invasive alien species (IAS) may be responsible for various, and potentially very important damages to Nature and societies (review in Pysek et al. 2020). For instance, they may deeply imbalance ecological networks and threaten local species (e.g., Gallardo et al. 2016). As such, biological invasions are considered as one of the leading causes of biodiversity erosion on the planet (Bellard et al. 2016). They are also responsible for the worldwide dissemination of pests for crop and food stocks (e.g., Wan & Yang 2016) as well as pathogen reservoirs and vectors (Young et al. 2017; Roy et al. 2023), thus heavily endangering food security, human and animal health (reviewed in Pysek et al. 2020). Invasive species may also have deleterious impacts on public, domestic and industrial infrastructures and equipment (e.g., Drummond 2001; FHA 2021). The average annual economic costs associated with bio-invasion damages and management was recently evaluated to be close to USD 30 billion, this value being most probably largely under-evaluated (Diagne et al. 2021).

By essence, transport of goods and people plays a central role in the dissemination of exotic organisms, hence biological invasions (e.g., Suarez et al. 2001; Ascensão & Capinha 2017). In particular, maritime trade has been playing a major role in long-distance dispersal of invasive species (Seebens et al. 2013), from the early oceanic migration phases (e.g., Matisoo-Smith and Robbins 2004; Tollenaere et al. 2010) through the Road to the East Indies and the European overseas expansion (e.g., Scheffrahn et al. 2009), to the most recent intensification of large ship-mediated exchanges (Ojaveer et al. 2018). Furthermore, global shipping traffic is expected to

increase in the coming decades, thus potentially leading to a 3- to 20-fold increase of biological invasions in some regions by 2050 (Sardain et al. 2019). In other words, maritime trade has long been, remains, and will continue to be a key driver of bioinvasion processes; as such, it should be considered as a primary target for the implementation of IAS management. Unfortunately, awareness, motivation, scientific knowledge and resources are often too limited to trigger operational actions. There is indeed a lack of collective multi-stakeholder public-private viable economic model to fund durably IAS surveillance and control, which requires (i) a supportive policy/regulatory framework that stimulates action, and (ii) academic activities tightly linked to very operational ones.

1.2. Legal regulations as a starting point for action

Bioinvasion-associated societal challenges are so important that international regulation texts have been flourishing during the last two decades, many of them being produced by UN sectorial agencies. These texts are crucial as they provide the legal grounds which legitimate -and push for- actions by socio-economic stakeholders and policy makers. Expectedly, most of these reference texts largely emphasize, or focus on, maritime trade-associated risk of biological invasions.

For instance, the World Health Organization (WHO) has formalized its third edition of the International Health Regulation (IHR) in 2005 (WHO 2005). IHR is inherited from a long series of debates and texts that trace back to more than a century ago (Lembrez 1966; Howard-Jones 1975). It dedicates a significant amount of sections on the management of IAS at national entry points, with a special emphasis on mosquitoes and rodents (vectors and reservoirs of zoonotic pathogens, respectively) in seaports. In particular, IHR imposes governments to implement active surveillance and management of IAS within seaports as well as 400 m around. It also enforces the sharing of data on invasive reservoir and vector species with WHO.[1] Of course, states may transfer the responsibility and action obligation to local stakeholders, such as seaport authorities, through national regulations and procedures.

Similarly, the International Maritime Organization (IMO) has produced the Ballast Water Management (BWM) international convention[2] that came into force in 2017. The latter provides a series of operational recommendations and calls for their application by ship owners and seaport authorities in order to control IAS dissemination through ballast waters and biofouling, two major processes of biological invasions (Hewitt et al. 2009).

Another example comes from the agriculture and food sector with the International Plant Protection Convention (IPPC) of the Food and Agriculture Organization of the United Nations (FAO): it develops International Standards for Phytosanitary Measures and gives concrete recommendations for their implementation to ensure food security and to reduce the IAS-associated threat to agriculture and plant biodiversity (Schrader & Unger, 2003).

International regulation texts co-edited by several UN agencies remain rare, but the IAS issue is now increasingly perceived as an inter-sectorial one. Accordingly, guidelines to set up legal frameworks and institutional networks exist beyond sectorial barriers (e.g., Clare et al. 2000). Following an initiative of the Convention on Biodiversity (CBD), the Inter-Agency Liaison Group

[1] Article 19

[2] see https://www.imo.org/en/ourwork/environment/pages/ballastwatermanagement.aspx

on Invasive Alien Species (IAGIAS) was created in 2010: it aims at facilitating dialogue among international organizations in charge with IAS management, as well as promoting cooperation, especially at national levels[3]. Note that, up to now, WHO does not belong to the IAGIAS.

By their sole existence, these international conventions, agreements and networks indicate an increasing awareness at higher institutional levels and allow and push decision makers to launch operational programs aiming at IAS monitoring and control.

1.3. Benin as a West African case study for the management of maritime trade-associated bioinvasions

Benin is located along the Guinea Gulf. Its coastline is narrow (120 km long), but the local seabed topography makes it a favorable place to access this part of West African coast by sea. This section of the "slaves' coast" was among the most active regions during the 16th-19th centuries trans-Atlantic trade (Lovejoy 2012). From the end of the 19th century, the French colonizers targeted the actual location of Cotonou (that was initially used as a slave regrouping site before embarking them towards the Americas) to settle their main import/export port (Ciavolella and Choplin 2019). Nowadays, the city is the largest of the country and it still shelters its only international seaport that has greatly developed within the last decades (Janin 1964). At the time of writing, more than 1000 ships dock there annually, and the overall cumulative amount of exchanged merchandises averages 11 million tons, with importations representing the largest part[4]. As such, the CS is a critical driver of Benin's economy, contributing to 90% of the international trade and generating up to 60% of the Gross Domestic Product[5]. Furthermore, it serves as a sub-regional maritime hub towards landlocked Sahelian countries such as Mali, Burkina-Faso, Niger (for which it is the first transit seaport) and Chad as well as towards the neighboring Nigeria – these countries represent half of the trade implicating PAC.

Most international UN-depending regulation texts dealing with IAS (e.g., WHO/IHR; CBD; FAO/IPPC) apply to Benin, which signed and sometimes ratified them. For instance, the country has recently ratified the IMO/BWM convention. *De facto*, it has to follow rules of several sub-regional conventions, such as the West African Economic and Monetary Union which imposes its member states to prevent and to control the propagation of pest organisms and plant-damaging animals[6]. In addition, though not specifically targeting biological invasion and their specific eco-evolutionary processes and dynamics, some national laws may encompass IAS-related issues, especially those about environmental[7] and phytosanitary rules[8]. Altogether, these constitute an actionable arsenal that can easily be mobilized by local stakeholders and decision makers to implement bioinvasion control policies.

Unfortunately, stakeholders' awareness appears low in Benin, and this results in a quite limited number of IAS surveillance and management actions (Adamjy et al. 2020). It parallels the rarity of scientific data about bioinvasions in the country since only little academic research was

[3] https://www.cbd.int/invasive/lg/
[4] Statistics and Economic Studies Service, SOBEMAP
[5] see the Government Program "Revealing Benin", https://beninrevele.bj/projects/port/
[6] WAEMU, regulation n°007/2007/CM/WAEMU
[7] e.g., law 98-030 from 1999
[8] e.g., law 91-004 from 1991

conducted locally.[9] This leads to a poorly documented record of invasive species that may proliferate on the national territory: as an illustration, in November 2018, the comparison of three international (namely CABI, GISD and GRIIS) and one national (DGRFN Bénin, 2014) reference lists showed that no species (out of 106 in total) were common among the four lists, while only 5 and 13 were common to three and two lists, respectively (Adamjy et al. 2020). Yet, in 2010, the national 2011-2020 Strategy for Biodiversity had already pointed towards a lack of data that needs to be filled, particularly about the diversity and geographic distribution of IAS in Benin (DGRFN Bénin 2014).

2. AN EXAMPLE OF SCIENCE OPERATIONALIZATION

2.1. From research to action: the main steps towards the setup of the PPSE, an innovative public-private multi-stakeholder tool for an effective and sustainable management of IAS

Date/Period	Marking event	Consequences in terms of partnership and project implementation
2013-2014	Regular demands for CS access authorization to conduct research with the seaport	First but punctual academic field work conducted by EPAC inside the seaport for independent research
Since 2018	Reactivation of sustained research on IAS in Cotonou seaport	EPAC and IRD academics and CS Environment Service learning to know each other
May 2018	Agreement between ACS and Antwerp Seaport for a delegated management	Start of a favourable institutional context
Sept. 2018	Meeting between EPAC and IRD academics and CS authorities	Authorized access to the seaport for academic field work explicitely conducted on bioinvasions; reinforcement of relationships between academics and CS Environnement Service staff; CS authorities awareness increased
Oct. 2018	Worshop to promote awareness on IAS-associated issues co-organized by IRD academics and CS Environment Service	Several portuary stakeholders (including staffs, head and future head of the CS Environment Service) participated; awareness greatly increased
Nov. 2018	Side-event on IAS-associated challenges in Africa during COP14 Biodiversity in Egypt	Participation of both IRD academics and ACS Environment Service head; first written PPSE proposal formalized and proposed to CS authorities

[9] e.g., pasture-associated plants: Aboh et al. 2008; crop-damaging insects: Goergen et al. 2016; Aïkpon et al. 2021; Ibrahima et al. 2021; cattle ticks: Biguezoton et al. 2016; commensal rodents: Hima et al. 2019; Badou et al. 2024, 2023; rodent-borne pathogens: Castel et al. 2021.

Dec. 2018	Scientific symposium on IAS in Cotonou	Academics from IITA participated, and formally invited to join the PPSE project by historic academic partners (EPAC and IRD)
March 2019	Following suggestion by academics, CS Environment Service head invited at WHO expert meeting on rodent control in Lima, Peru	Increased visibility of the PPSE project; consolidation of CS-academics collaboration and mutual trust
18 July 2019	Principle Agreement signed between CS and two academics partners	Mutual recognition of partnership, and explicitly recognized basis for launching of the PPSE project
End of 2019 / 2020	Collaborative work on building plans, budgets, etc; beginning of ENABEL involvement in the process and funding of PPSE phase I; order of new field and lab equipment	First truly collaborative work (here, first steps of PPSE setup); full involvment of Enabel, one of the main funder of PPSE projetc
Feb. 2020	Workshop to increase awareness of seaport and seaport-connected stakeholders on IAS issues	First formal presentation of the PPSE project to socio-economic stakeholders
June - Dec. 2020	IRD-funded project on the setup of a business plan for PPSE	Preliminary assessment of putative opporunities for PPSE sustainable networking and self-funding
Oct. 2020	Tender process for PPSE equipment acquisition opened by Enabel	The setup of the PPSE lab is concretly launched
Dec. 2020	First draft of the PPSE project phase II, including financial and logistical aspects	Further improving the roadmap for concrete implementation of the lab/activities
Jan. - May 2021	Adjustement of the PPSE phase II project following co-construction with ENABEL in Benin	Consolidation of CS, academics and ENABEL funder partnership; learning to interact and to work together
2021	Fitting operations for PPSE premises	Obvious proof of the CS motivation and wish of long-term involvement
June 2021	Submission of PPSE phase II to ENABEL Belgium for funding	All partners expecting together
Oct. 2021	Joint ACS-academics talk given at the Montpellier Global Days conference in France	First formal collaborative contribution at an international level; increased partnership and mutual confidence; increased visibility
10 Oct. 2021	Partnership convention officially signed between academics	Officialization of the PPSE project; enrollement of the last academic partner (CREC)

21 Oct. 2021	Funding convention signed between ENABEL and IRD	Pending administrative procedures, PPSE first activities are funded, and can start for good
Dec. 2021	PPSE experts attend the WASABI conference in Senegal	Increased visibility of the PPSE project and activities towards an international academic audience
Dec. 2021	PPSE experts attend the VectoPole conference in France	Increased visibility of the PPSE project and activities towards an international academic audience
Nov. & Dec. 2021	Setup and testing of PPSE equipments, as well as PPSE staff training by IRD experts	Capacity building of PPSE staff
3 Dec. 2021	Official inauguration of the PPSE	The PPSE is officially existing, and presented to the media
Since 2022	PPSE activities start	PPSE produces its own data and knowledge
March 2022	PPSE-organized workshop on IAS issues to increase socio-economic awareness	Several portuary stakeholders participated; awareness greatly increased; increades visibility of PPSE towards socio-economic stakeholders
April 2022	PPSE staff attend to the Environmental Commission of Cotonou Seaport	Increased visibility of the PPSE towards seaport stakeholders; recognition of the PPSE as a legitimate stakeholder by the seaport authorities
Sept. 2022	PPSE experts attend the PAMCA conference in Rwanda	Increased visibility of the PPSE project and activities towards an international academic and non-academic audience
Nov. 2022	PPSE experts attend the ObsMICE conference in Niger	Increased visibility of the PPSE project and results towards an international academic audience
Dec. 2022	PPSE staff attend to the Environmental Commission of Cotonou Seaport	Consolidated visibility of the PPSE towards seaport stakeholders; recognition of the PPSE as a legitimate stakeholder by the seaport authorities
July 2023	Setup of new techniques and PPSE staff training by IRD experts	Capacity building of PPSE staff
Sept. 2023	PPSE experts attend the ASMS conference in Namibia	Increased visibility of the PPSE project and activities towards an international academic audience

Sept. 2023	PPSE staff attend to the Environmental Commission of Cotonou Seaport	Consolidated visibility of the PPSE towards seaport stakeholders; recognition of the PPSE as a legitimate stakeholder by the seaport authorities
Sept-Nov. 2023	Almadius expertise	Assessment of PPSE organization and functioning, and investigation of possible strategies for PPSE sustainable (and self-funded) future
Oct. 2023	PPSE-organized workshop on IAS issues to increase socio-economic awareness	Several portuary stakeholders participated; awareness greatly increased; increades visibility of PPSE towards socio-economic stakeholders
Nov. 2023	Phase II of Enabel funding ends	Assessment of PPSE first years of functioning is available
Nov. - Dec. 2023	Discussion about Phase III of Enabel funding starts between PPSE-involved stakeholders	New goals are defined towards PPSE sustainability on the long-term
Dec. 2023	Report of Almadius expert firm provided to PPSE, Enabel and CS autorities	Different well-documented scenarii and guideleines are proposed in terms of legal structure, functioning and business plan for the PPSE to reach sustainability and self-funding.

Table 1. Chronological list of some of the most critical steps/events that led to the PPSE conception, setup and valorization (up to end of 2023).

"What is relevant is the short circuit established between many groups usually uninterested by what happens inside laboratory walls, and laboratories usually isolated and insulated from such attention and passion." Bruno Latour (1983)

From 2013 onwards, the CS opened its gates to a group of researchers from Abomey-Calavi Polytechnic School (EPAC, Cotonou) and the French National Research Institute for Sustainable Development (IRD), thus allowing them to sample within the seaport area. This rare opportunity of scientific investigations within the closed gates of a very strategic seaport was instrumental to the whole following sequence of events, and it was permitted by the contacts already established by Gualbert Houemenou (EPAC) and his students in order to work on CS rodents. This access was then proved to be an opportunity to monitor zooplankton species within the seaport basin (Avocegan and Ouinsou, unpublished results), to identify newly introduced rodent species (Hima et al. 2019), to conduct studies on longitudinal ecological surveys of invasive *vs*. native rodents (Badou et al. 2024), on genetic diversity and structure of invasive population of rodents (Badou et al. 2023) as well as on newly introduced rodent-associated pathogens (Castel et al. 2021).

For the researchers, this collaboration resulted in many back and forth between the laboratory and the CS settings that fueled informal but regular interactions with the CS workers and the residents near the seaport area. These interactions allowed academics to reach a better understanding of the CS socio-ecological system: working environment and practices, informal and formal economic activities, relationships between humans and rodents, etc. On the other side,

the comings and goings of the researchers between their laboratory and the field resulted in a change of the perception that people had of rodents and rodent-related issues. For example, the researchers gave some informal advice to the workers in order to prevent the proliferation of rodents, which often led to some subsequent perceptible changes of practices (e.g., wide-scale cleanings of abandoned goods within industrial storehouses).

These comings and goings between the small laboratory scale and the large field scale can be named "translations". Little by little, these interactions evolved until they resulted in formal interactions and the subsequent setup of the PPSE. We will here spell the narrative leading to this achievement by describing four determining steps according to the model of the translation sociology (Callon, 1986). This sociological field is a process-oriented, social and collaborative practice involving human and non-human actants that strive to achieve certain objectives.

The first step, namely « problematization », is the process of transposing researcher's laboratory knowledge into the stakeholders perspective: the scientists become indispensable because they convince the stakeholders that their researches match their interests. The second step, called « interessement », is the stabilization of the problematization step: the stakeholders' identities and interests are defined by the scientists according to their interpretation of the problem. However, the interessement phase does not always lead to stabilized alliances and it is only when it is achieved that the third step « enrolment » is reached. It is the device by which the role of each stakeholder is attributed by a series of negotiations. Finally, the fourth step is the « mobilisation » of allies: it occurs when each group of stakeholders have influential spokesmen, that can really represent the different entities they speak for.

These four steps are described here below with regards to biological invasions issues in Benin and within the CS as well as to the origin and implementation of the PPSE.

2.1.1. Step 1: Problematization

"He who is able to translate others' interests into his own language carries the day." Bruno Latour (1983)

Gualbert Houemenou (EPAC) and his students managed to underline and to quantify the damages induced by rodents on rice products but, at that time, they never communicated about their results directly to the CS authorities (this work was published later on; see Dossou et al. 2020). Nuisances caused by rodents were already known by the seaport workers, but researchers provided a quantitative economical cost corresponding to these damages. Other scientific results were obtained on other aspects. In particular, three were related to human health issues and contributed to profoundly modify the way the CS authorities perceive the rodent problem: (1) the seaport is an entry door for invasive rodents coming from foreign countries (Hima et al. 2019); (2) some of these rodents carry diseases that can be transmitted to humans (e.g., Castel et al. 2021; Etougbétché et al. 2023), thus potentially fueling local epidemics; (3) there is an international and national legal framework that could point the responsibility of the seaport authorities in terms of invasive species management and potentially related problems (Adamjy et al. 2020).

These results were important in that they reshaped the IAS problem definition: the invasive rodents were not only a nuisance but were also a threat to the health of Beninese people. Moreover, these rodents were not native from Benin but of exotic origin, and they came with docking ships.

Consequently, this called for surveillance and new preventive actions against their installation, not only their proliferation.

There were three main stakeholders involved at that stage, then: CS authorities, IRD and EPAC academics as well as the rodents (native and invasive) that caused different types of damages. The researchers managed to convince CS authorities that they had common interests: knowing more about the populations of rodents would benefit scientific knowledge by providing new insights into population dynamics, ethology and ecology, and it would benefit CS authorities by giving appropriate advice to prevent their introduction and proliferation, thus helping in damage costs reduction and other rodent-associated risks mitigation.

2.1.2. Step 2: Interessement of seaport authorities and economic stakeholders

When the CS stakeholders became aware of the three findings mentioned above, the researchers became indispensable to address the rodent issue. Indeed, the rodent issue had turned into an IAS issue, and the researchers were those who possessed the precise knowledge on the process of biological invasion. In their lab, they could bring to light previously invisible diseases (e.g., Castel et al. 2021; Etougbétché et al. 2023), and, thanks to genetic analysis, they could determine which rodents were introduced, and which ones were not (Badou et al. 2024).

Local pest control companies previously enrolled for rodent control campaigns were no longer sufficient to handle the rodent issue since the problem was then defined as not only a technical matter, but as a complex entanglement between technical, scientific, political and legal considerations. Furthermore, due to the exotic origin of CS rodents, the thinking had to be extended to other non-rodent species that might also invade Benin through the ships, such as crop pests, mosquitoes and aquatic species carried in the ballast waters. Adding new species into the definition of the problem also meant including new stakeholders with corresponding interests, knowledge and skills.

From 2019 to 2023 (Tab. 1), meetings and activities gathering CS staffs and academics were conducted in an increasingly collaborative manner, starting from research results explained to CS authorities and socio-economic stakeholders (e.g., invitation to attend several sessions of the CS Environmental Commission), through awareness events to operational partnership (e.g., through two dedicated workshops) towards formal implementation of IAS management, namely the setup of the first Seaport Platform for Environmental Surveillance in Africa, and beyond.

2.1.3. Step 3: Enrolment

The list of stakeholders involved in the process grew along with the widening of the problem definition. Other researchers were enrolled to encompass appropriate knowledge, skills and credibility on each identified aspect. At the end of year 2018, the International Institute of Tropical Agriculture (IITA) was asked to join the project in order to deal with the invasive insects that may disseminate with imported/exported food stocks. At the end of year 2020, the Entomologic Research Center of Cotonou (CREC) was asked to participate the project to address the mosquito vector-associated sanitary risks issue, while colleagues from the Science and Techniques Faculty (FAST, Abomey-Calavi University) joined to bring their expertise in molecular biology.

Proving that invasive species coming through ships could create major damages on food and health security, involving seaport authorities as (at least partly) legally responsible was a turning point in defining the invasive species issue as a matter of public national interest. Therefore, it allowed seaport authorities and researchers to interest development agencies.

"At first, the monitoring of invasive species, considering the damages they could cause, seemed to us like an interesting angle"[10] Hervé Corbel, Enabel, interview from the 12th of April 2023 (translated)

An important but independent eco-political event was critical for the collaborative process that translated into the PPSE implementation *per se*: in May 2018, the management of Cotonou international Seaport was delegated to the International Port of Antwerp, Belgium. This was accompanied by a boost in Benin-Belgian cooperation, hence Belgian investments (essentially through the Belgian Agency for Development, Enabel) in the country, with particular attention paid to seaport-connected aspects. Accordingly, Enabel accepted to support the setup of the PPSE in three successive phases: funding of lab equipment[11] and funding of the first years of functioning[12].

2.1.4. Step 4: Mobilization

This step focuses on the question of "spokesmen": who speaks in the name of whom? Indeed, institutions were mentioned, but during the process described here, only a few individuals speak in the name of their respective institutions. Mobilization is about this particular issue, i.e. do the few individuals who are engaged in the process really speak for their whole group? Staff from seaport authorities, Enabel and academics who were key resources and who made different agreements and negotiations that finally gave birth to the PPSE, had to be stakeholders with sufficient credibility to enroll their institutions, hence to be legitimate spokesmen. There was a need of alignment between their respective interests and the strategy of their belonging institutions. For instance, at the same time as the PPSE development, the CS authorities also planned to reshape and/or to rebuild a large part of the seaport infrastructures. There was therefore an opportunity to include in this reconstruction plan a building that could host the PPSE. The CS authorities were also in the process of being more and more compliant with international standards regarding security, environmental and social aspects of the seaport infrastructures and activities. The PPSE thus became an excellent argument for the CS authorities to show their will to act towards, and to appear as a more sustainable, "eco-friendly" harbor.

Concerning Enabel, who permitted the existence of the PPSE thanks to an important funding support, the support of the platform was a straightforward way for interacting more closely with the Belgian CS authorities. It was also an opportunity for Enabel to collaborate with local partners (e.g., EPAC and CREC) on a project that was innovative, visible as well as in straight line with its strategic priorities. Accordingly, it was presented in several international workshops and is an object of interest for several first line actors.[13] For instance, PPSE partners participated jointly

[11] phase I, 2020-2021
[12] consumables, contracts, etc.; phase II, 2021-2023; funding convention signed on the 21st October 2021; phase III, 2024-2028, currently under discussion
[13] e.g., the WHO through the International Health Regulation

to a panel for a side-event dedicated to bioinvasions in Africa at the Biodiversity COP 14.[14] In the same manner, following the recommendation of a PPSE-involved academics, a CS representative was invited to a WHO expert workshop on rodent control (Lima, Peru, March 2019; Colombe et al. 2019). The PPSE was also presented at the New Africa-France Summit[15] by an academic / non-academic duo of PPSE staffs (Tchabi and Dobigny 2021).

Obviously, such a visibility was win-win for all PPSE-involved stakeholders, namely the local academics, IRD, CS authorities and Enabel.

Several important agreements were signed among all these partners in order to have things fully formalized[16]. Equipment was ordered during 2020 thanks to a first Enabel contribution. A second Enabel grant was then provided to IRD that was in charge with the follow-up of the PPSE functioning during the two first years.[17] The PPSE was installed in brand new premises, then officially launched on the 3rd December 2021.[18] Finally, a third workshop[19] was organized in March 2022 in order to present officially the PPSE to socioeconomic stakeholders, to keep communicating about newly acquired scientific results as well as the legal obligations about IAS. The objective was to inform them about the existence of the PPSE, and to show them that it may be useful for them and their respective businesses or tasks.

2.1.5. Step 5: Translation

These alignments seem stable since the official opening of the PPSE. Research is still ongoing, and CS authorities, Enabel and academics now speak in the name of the PPSE, thus confirming these institutions all took ownership of it. There could even be tensions, for instance if one of these institutions' name is left out when communicating about the PPSE.

However, Callon (1986) reminds us that when there is translation of all these interests, there may also be treason. Indeed, the win-win alignment that is described hereabove could be questioned and destabilized at any moment. For instance, the funding issue is crucial, and lack of resources could rapidly imbalance the whole process. This is the reason why the building of a business plan that would allow the platform to be financially self-dependent has been identified as a priority. Accordingly, IRD (2020-2021) then Enabel (2023; coll. Almadius expert firm, Belgium) hired external experts that worked on such a business plan that is expected to produce guidelines as well as legal and operational targets towards increased formalization and financial autonomy of the PPSE (Almadius report, unpublished). This second phase of the PPSE existence will probably require the enrolment of new stakeholders, especially economic operators that may be asked to participate in the funding of the PPSE in the coming years, thus requiring to run a new interessement-mobilization-enrolment-translation cycle. This second phase towards self-functioning will be accompanied by a third batch of Enabel funds whose concrete implementation (2024-2028) is still under debate at the time of writing.

[14] Sharm-el Cheikh, Egypt, November 2018
[15] Montpellier Global Days, Montpellier, France, 4th-7th October 2021
[16] e.g., convention on principle agreement for a CS/EPAC/IRD partnership signed on the 18th July 2019; CS/Enabel/EPAC/IRD/IITA/CREC partnership convention signed on the 10th October 2021
[17] IRD/Enabel convention BEN1803811-10103, signed on the 20th September 2021
[18] https://www.ird.fr/la-plateforme-portuaire-de-surveillance-environnementale-ppse-est-inauguree
[19] https://www.ird.fr/lird-sensibilise-les-acteurs-de-la-plateforme-portuaire-de-surveillance-environnementale

It is therefore important to keep in mind that the PPSE is not an immutable object: it builds on a dynamic, potentially fragile equilibrium, on the credibility of a few spokesmen as well as on the alignment of positive situational elements, including the convergent interests of the stakeholders enrolled to date. One of the ways for the PPSE to gain legitimacy and sustainability is to be fully appropriated by an extended range of stakeholders. This can only be achieved by the production of regular and concrete evidence of the benefits brought by science-guided monitoring and management of IAS.

2.2. What is the PPSE about?

2.2.1. Description of the PPSE

At the time of writing, the Seaport Platform for Environmental Surveillance in Cotonou consists in a lab (Figure 1a-f) where a panel of CS Environment Service staffs, UAC (coord. G. Houéménou, H. Akodgbo & A. Missihoun), CREC (coord. R. Aikpon) and IITA (coord. G. Goergen & E. Dannon) academics and their students and postdoc fellows implement field surveys and experimental analyses that aim at monitoring pest organisms within the seaport area, with a special emphasis on invasive ones. To date, particular attention has been given to rodents and their associated zoonotic pathogens (Dossou et al., 2020; Castel et al., 2021; Badou et al., 2023, 2024; Etougbétché et al., 2023; coord. EPAC and IRD), food stock-damaging insects (M. Kindomissi, PhD thesis, 2022-2025, coord. IITA), human pathogen-vectoring mosquitoes (A. Lokossou, PhD thesis, 2022-2025, coord. CREC) and zooplanktonic organisms (F. Ouinsou, MSc thesis, 2022-2023, coord. EPAC). Surveillance relies on regular collects in CS sentinel sites and subsequent taxonomic identifications performed in the lab using microscopy or molecular biology. Extra activities include serologic and genetic analyses that allow PPSE to survey some rodent- or mosquito-associated pathogens, to investigate resistance to pesticides, or to identify eradication units. Altogether, data and results produced by the PPSE are expected to help CS authorities to tailor and to implement efficient as well as environmentally and economically sustainable IAS management strategies.

Figure 1. Pictures of: (a) the PPSE building and (b, c) molecular biology lab, (d) rodent trapping within the seaport, (e) microscopy-based identification of mosquitoes at the entomology facilities, (f) food stock-infesting insects campaigns within the industrial storehouses, and (g) collect of zooplankton from ballast waters of a docked ship.

The lab works under the CS Environment Service (coord. A. Tchabi, 2018-2022; current coord. R. Akanni-Ediko) while scientific activities are coordinated by an academic expert (current coord. G. Houéménou, EPAC). A steering committee gathers three times a year to design, supervise and follow-up all field, lab and communication actions. The field and experimental investigations are conducted by MSc and PhD students as well as postdoc fellows supervised by IITA, CREC and EPAC academics involved in the PPSE. IRD/CBGP colleagues help in coordinating and running the platform (technical, logistical and financial aspects) and they are also involved in awareness campaigns towards socio-economic stakeholders as well as capacity building plans (e.g., transfer of protocols, lab management, etc.). In addition, external collaborators[20] were contacted to be resource people who now brainstorm on a regular basis with the PPSE staffs. Their expertise may also complete analyses that cannot be performed locally yet, in order to facilitate the follow-up of the protocols and procedures as well as to guide further technological development of the PPSE through capacity building and reinforcement. Indeed, the explicit objective of this international and local consortium is to evolve to a local, fully financially, scientifically and operationally autonomous structure.

[20] e.g., VetAgro Sup, Lyon, France; IRD/MARBEC and IRD/MIVEGEC, Montpellier, France; Douala University, Cameroon

In the same line, equipment and functioning have been funded by Enabel (through IRD) for the few years to come (PASPort 2021-2023, with extension to 2028 being currently discussed), but financial autonomy (and self-generation of its own funds for functioning) is an explicit target to be reached in the coming years. This is why a business model has been prepared (coll. Almadius, unpublished; see above), exploring how PPSE activities could be funded by seaport activities and involve economic stakeholders (e.g., ship owners, seaport infrastructure users, etc.).

2.2.2. Communicating on the PPSE experience and using it as a leverage towards broader actions and awareness about the IAS-associated issues

Since prevention of new invasions appears more efficient and cheaper than riposte to already expanding and impacting invaders (Diagne et al., 2021), an action focusing on surveillance, early detection and control of newly introduced propagules was preferred, as recommended by IPBES experts (IPBES, 2023). The main barrier to this achievement was the very low awareness of local policy makers and socio-economic stakeholders that needed to be convinced and enrolled for the PPSE to be successful (see section 2.1). It was then decided to rely on various communication events, such as national TV shows (e.g., ORTB2 channel, 24th and 26th June, 2019). In addition, a project of video reportage aiming at informing a wide audience on the socio-environmental impacts of biological invasions in Benin was started with local scientific film makers (on progress).

Of course, scientific talks were given to several academic audiences, such as at the first West African Symposium on Biological Invasions[21], the 8th Pan-African Conference on Mosquito Control[22] or the 14th African Small Mammal Symposium.[23] Such meetings may offer unexpected opportunities: for instance, during one of these conferences, PPSE representatives were contacted by a private company interested in future collaborative insecticide and rodenticide tests within the PAC settings (but with no follow-up since then).

At a wider scale, the PPSE initiative was put forward during different major events of the international agenda to promote IAS surveillance and management.[24]

2.3. Constraints, challenges and opportunities

The first service that the PPSE is expected to provide is the detection of newly introduced IAS in order to trigger rapid response from PAC authorities and socio-economic stakeholders. By essence, it requires to distinguish between native and invasive species (and, ideally, to detect new propagules of an invasive but already present species) in Benin. This can be achieved only through robust taxonomic identifications (or, in the case of new propagules, population characterization). However, though theoretically obvious, this is not always an easy task. Indeed, as already stated above, data about IAS are limited in Benin (Adamjy et al., 2020; see above), with many invasive species probably already present but still undetected. In addition, in some taxa, it may be quite difficult to identify exotic organisms due to the lack of reference records of native species. The example of zooplankton is noteworthy: among the many samples that were collected within the

[21] WAS@BI, 14th-17th December, 2021, Saint-Louis-du Sénégal, http://thewasabi.net/
[22] Kigali, Rwanda; September 2022, 26-28th
[23] Swakopmund, Namibia; September, 2023, 18th-22nd
[24] e.g., COP14 in Sharm-el Cheikh, Egypt, 2018; WHO expert workshop on rodent control, Lima, Peru, 2019; the New Africa-France Summit, Montpellier France, 2021; see above

seaport basin, only a quarter could be unambiguously identified at the species level on morphological grounds on the PPSE due to the scarcity of data from the Guinea Gulf (Ouinsou et al., unpublished results). Obviously, the monitoring of this particular group will require technological development (e.g., DNA barcoding approach) and an important effort to produce a reference database. In a more general manner, baseline data for Cotonou seaport biodiversity are needed for the PPSE to be able to detect any newly introduced species. This is why reliable local inventories of monitored organisms (e.g., rodents, insects, marine invertebrates and planktonic species, etc.) are mandatory first steps. As an example at the sub-specific level, a microsatellite-based genetic dataset was recently produced for house mice, black and Norway rats from the seaport and now allows for the detection of newly introduced individuals of these invasive but already present species (Badou et al., 2024).

As often when new structures/services are created, their perpetuity strongly depends on long-lasting funding. At the moment, the PPSE initiative functioning is fully supported by external funds[25] while fluids and buildings maintenance are supported by PAC. Interestingly, research grants were obtained on particular aspects of IAS-associated issues,[26] thus contributing to fuel PPSE activities. However, the chances that PPSE regular activities are fully supported by applied research grants are weak, and relying only on this mode of funding would probably be risky. This is why the business model and plan for the PPSE that are currently under investigation (coll. Almadius expert firm; see above) will be critical. A special attention must be paid on opportunities for self-funding, which will probably be favored by international and national regulations that constraint socio-economic stakeholders by law to be involved in IAS surveillance and management (see section 1.2).

Concomitantly, an important effort was put on raising awareness of socio-economic stakeholders on the impacts of IAS. Having them fully aware and concretely involved would prove their interest in the PPSE initiative, and their willingness to support it. Firstly, the CS authorities themselves must stay convinced that the PPSE initiative that they have accepted to house and to support is worth it. As a first promising example, once imported rodent-borne pathogens were identified at CS (i.e., Seoul hantavirus: Castel et al., 2021), an investigation of this new medical threat among the seaport workers was planned jointly by the seaport occupational service, external academics and PPSE (HANTARIS project, coord. G. Castel, ANSES, 2022-2025). Economic agents operating within the CS should also be convinced. Accordingly, important efforts are currently put on rodent management, as rodents were quoted as a first line pest organisms for SOBEMAP activities.[27] In a more general manner, collaboration with public services should be called for and pushed since it is expected to facilitate political support, hence PPSE sustainability. For instance, agricultural entomology surveillance actions are conducted in close collaboration with Ministry of Agriculture phytosanitary services that oversee the control of pest insects in imported/exported goods.

Beyond social engagement and ethics, one may expect that the costs associated with IAS-induced damages may provide further convincing arguments for economic stakeholders to invest

[25] i.e., PASPort project, Enabel funding, 2022-2023; second phase 2024-2028 under discussion, see above

[26] e.g., HANTARIS project on imported rodent-borne hantavirus and their risk for human health, including PAC workers; ANSES, France, 2023-2026

[27] SOBEMAP is a national society in charge of merchandises handling and, as such, one of the most important economic and operational PAC partners

in IAS control (Diagne et al., 2021). From this perspective, the implementation and good communication on research-guided evidence about such costs, as well as proofs of concepts of the operational solutions that should be deployed, are critical. This is the reason why new surveillance and control methods are tested on-site, regular workshops are planned by the PPSE staff, and media coverage is strongly encouraged.[28]

Another crucial challenge that may face the PPSE is the availability of expert workforce. Up to now, three post-doctorate fellows, two PhD and one MSc student have been in charge with everyday field, lab and *in silico* activities of the PPSE. Although this team is supervised by four Beninese academics (from FAST, EPAC, CREC and IITA) and technically accompanied by international partners (essentially IRD), no clear plan exists yet to make their positions permanent. However, on the long term, if external funding was to end, their contracts would stop and the PPSE activities would probably have to stop, too. This makes the whole project quite vulnerable. This is why, among other elements, the recent business plan (coll. Almadius expert firm; see above) takes permanent staffs' salaries into account. Until then, an extended funding opportunity is currently under discussion with Enabel to have the PPSE workforce perpetuated at least for the five coming years, with a gradual shift towards independent and sustainable funding as an explicit target (see above). By essence, this also raises the question of the legal status of the PPSE. The recent analysis of the Almadius expert firm suggests to set it up as an Association. This administrative clarification will help to select the most adapted type of governance and funding of the PPSE on the long term.

Another important challenge for the PPSE is that its main objective (i.e., avoiding bio-invasions) may be difficult to conciliate with some CS authorities' and partners' economic objectives. Maritime trade is highly competitive and seaports seek for rapid turn-over of ships in order to maximize volumes of imported/exported goods. This is particularly true along the Guinea Gulf where seven large international seaports compete within a <1,200 kilometers coastline.[29] Potential incompatibilities -when not obvious conflicts- between PPSE and CS essential objectives may exist. For instance, delays required to valuably investigate and/or secure shipments may sometimes be longer than those imposed by logistical as well as economic constraints (e.g., loading/unloading planning; docking times and associated costs; importation/exportation delays imposed by contracts; lifetime of some goods). It would be surprising that business activities be fully inflected by environmental issues only. Consequently, a permanent dialog between PPSE and CS stakeholders must be engaged in order to reach mutual understanding and to setup jointly some procedures allowing a balance between pure profitability on the one hand, and the respect of international environmental regulations on the other hand.

This should also be thought in terms of CS communication about a respectable, voluntarist and modern image that, in turn, may contribute to attractivity (i.e., shipping companies choosing port of Cotonou for efficiency and quality procedure), hence profit. This is why we believe an important effort is to be put in information campaigns through various mass as well as specialized maritime trade-focused media. However, communication should be carefully managed since the

[28] e.g., *aCotonou.com* online news on the 07/12/2021, http://news.acotonou.com/h/140847.html; *24hauBenin* online news on the 08/12/2021; two RFI podcasts on the 02/08/2022, https://www.rfi.fr/fr/podcasts/les-ports-du-monde/20220801-le-port-de-cotonou-se-modernise, and on the 08/08/2022, https://www.rfi.fr/fr/podcasts/afrique-%C3%A9conomie/20220808-surveillance-environnementale-un-laboratoire-in%C3%A9dit-au-port-de-cotonou

[29] e.g., San Pedro and Abidjan in Côte d'Ivoire; Takoradi and Tema in Ghana; Lomé in Togo; Cotonou in Benin; Lagos in Nigeria

detection of harmful invasive organisms within CS facilities can contribute to either a positive (e.g., "environment-friendly attitude") or negative (e.g., "entry gate for new troubles") reputation. Such an image will be important in reinforcing environmental arguments in face of often poorly compatible economic ones.

Finally, the PPSE credibility may be seriously ruined by processes that it cannot prevent on its own. An obvious example is illegal deballasting that may be responsible for massive release of exotic marine organisms. In such cases, only higher-level institutions can play a significant role. Nevertheless, the PPSE may once again contribute to increase decision makers' awareness and to foster their interventions through regular communication on IAS-associated issues.

3. CONCLUSION

To our knowledge, the PPSE of the Cotonou seaport is the first one of its kind, gathering both academics and operators within the same technological platform in order to tackle maritime trade-associated bio-invasions through science-guided actions. In that sense, it perfectly fits the recommendations and call for action by the recent IPBES experts panel (IPBES, 2023). As an emblematic initiative of sustainability science, it holds both promises and challenges. First, it has succeeded in sitting different stakeholders around the same table (e.g., CS staffs as well as handling and import/export companies; representatives of ministries and other national services; researchers and students). Second, from now on, it contributes to boost communication about bio-invasions and their socio-environmental consequences in Benin through various media – which, in a country where awareness on IAS is quite low (Adamjy et al., 2020), is an important achievement on its own. Third, it has already allowed to highlight several potential recent bio-invaders in Benin, such as the house mouse (Hima et al., 2019), the Brown rat-borne Seoul Ortohantavirus (Castel et al., 2021), a quarantine crop-damaging beetle (Kindomissi et al., unpublished data) as well as several zooplanktonic species (Ouinsou et al., unpublished data).

Nevertheless, its efficiency and viability remain to be tested and consolidated on the mid to long term. In particular, beyond monitoring, efforts are currently put on the implementation and the test of innovative management methods in order to avoid the introduction and/or proliferation of invasive organisms within the seaport facilities. This shift towards control methods appears important to us in order to propose concrete tools that economic operators and CS services could appropriate and implement. Altogether, further IAS interception and control will be required to increase and to maintain CS and CS-associated socio-economic stakeholders' confidence. Ideally, quantitative assessment of economic losses avoidance (e.g., through pre- and post-control surveys) and economic gains (e.g., through improvement and rationalization of management strategies) should be very useful to reach such a goal, hence to consolidate PPSE legitimacy.

From a structural perspective, the perpetuity of highly qualified work forces and self-funding ability will be the most essential challenge to face for the PPSE in the years to come. Solving these two issues on the long term will strongly depend on political motivation and engagement, hence PPSE visibility and efficiency in adequation with CS functioning and profitability.

Finally, once the PPSE will be recognized as useful and legitimate by all protagonists, it will be interesting to replicate this initiative elsewhere, developing it from local contexts. However,

in addition to the challenges described here above, such an upscale may also face another facet of international trade, i.e. the reluctance of CS authorities to share their expertise, hence to share with concurrent entities what is currently perceived by them as a competitive advantage.

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