18 December 2023 Discussion Paper[1]

Assessing the financial, commercial, and economic dimensions of a US National Aquatic eDNA Strategy

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Summary of recommendations

We recommend

1) Federal and/or private eDNA stakeholders **sponsor promptly a thoroughly researched study** on financial, commercial, and economic dimensions of aquatic eDNA. To move to a new level of decision-making, report information accurately at the June 2024 national aquatic eDNA conference about financial, commercial, and economic dimensions of aquatic eDNA, over a span of industries and applications.

2) The high-level working group of the Federal government concerned aquatic eDNA (OSTP/SOST) call upon its members and others **to estimate with reasonable precision public budgets relevant to eDNA**. Estimates should cover both actual expenditures on eDNA and expenditures on services that in future could be fulfilled in large part by the advancing technology of eDNA. Another option to perform such a study would be the Congressional Budget Office if a Member or Committee of Congress takes an interest.

3) Relevant US government agencies **consider potential for eDNA of Small Business Innovation Research (SBIR) programs**.

4) SOST and/or organizers of the June 2024 National eDNA conference **assemble a list of eDNA-related companies that SBIR programs of all agencies have funded** in recent years and engage the SBIR companies as conference participants, not only as sources of solutions but as sources of information on market sizes and niches.

5) Organizers of the 2024 national eDNA conference similarly **engage professional investors relevant to eDNA** including investors who have backed companies in the eDNA space broadly defined.

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7) Leaders of the incipient national network **subscribe to the most curated and complete databases of private corporate funding that may include eDNA** (such as Pitchbook).
8) Leaders of the incipient national network explore and **use patent databases and other such tools for the information they hold and as a channel to inventors in the eDNA space.** A thorough update on the status of patents and other facets of intellectual property in regard to eDNA would be a valuable contribution to the June 2024 conference.
9) Leaders of the incipient national network, **to make a rough estimate of the total number of eDNA samples processed globally**, undertake thought experiments. One experiment suggests 17,000 samples processed in 2022 for academic papers. Other thought experiments could **estimate the actual and potential dollar value of the global eDNA markets for goods and services**, including software. The actual totals involved at present are very likely modest, well under half a billion USD globally.
10) Analysts **develop forecasts of possible demand envisioning scenarios with both carrots (chances for profit) and sticks (regulatory requirements)** that might spur demand.

Rationale:

At the outset, we caution that the size of the market for eDNA cannot be ascertained directly, for reasons detailed below. However, we compiled some available indirect information, used back- of-the-envelope approaches to calculate what we believe to be defensible first estimations, and offer observations and suggestions for further refining the numbers. In some cases we offer names of potential contacts. We ourselves have not reached out to such individuals, who could be valuable sources of reliable numbers.

The USG is both an end-user and a seed funder of a handful of providers. As an end user, Federal budgets through FY 24 rarely if ever name "eDNA" in a way that allows one to compile Federal expenditures. This may begin to change with FY 25 and FY 26 budgets. In any case, it should be possible for OSTP/SOST to call upon its members and others to estimate with reasonable precision -- more than is available in public budgets. In thinking about the expenditures, two amounts should be held in mind. One is the actual present expenditure explicitly on eDNA.

The second, more important in the long run, is the expenditure on services that in future could be fulfilled in large part by the advancing technology of eDNA.

We offer NOAA as an example: NOAA has several units that could fulfill parts of their mission with services provided by eDNA, including its programs for marine sanctuaries, coral reefs, marine mammals, and fisheries. With regard to fisheries, the relevant line-item is broad: NOAA spending via NMFS for "Fisheries Data Collections, Surveys, and Assessments" has grown at a 6.2% annual rate since 2018, from $155mn in FY2018 to an estimated $222mn in FY2024 (page 81).

An exemplary study would analyze this budget in a granular way, considering what is spent on trawls (and other methods) and what is spent on eDNA and to what extent eDNA might grow, whether as a complement or substitute. Doing such analyses for the numerous relevant units of NOAA as well as the relevant units of the other Federal agency units participating in the SOST biodiversity working group would usefully surface the large network of potential Federal users. While the SOST WG could undertake this task, another option would be for a member or committee of Congress to request such a study by the Congressional Budget Office.

Thought experiments about the size of the global market or effort and the USA shares could follow from such a study. For example, a back-of-the-envelope exercise can ask the question: "what would the fisheries eDNA market size sum to if the rest of the world's governments spent an equivalent amount as the USA per sq km of EEZ ($19.62)?" The answer is $2.7 billion. Imagining that Iceland and Tuvalu are spending comparable amounts on data collection in their similarly-sized EEZs is not remotely accurate, nor the assumption that eDNA accounts for more than a tiny minority of fisheries assessment spending at present. Nevertheless, a series of such thought experiments might lead to conviction that the USA, for a range of applications, might be typically 10%-40% of the global market.

A careful take on the prospects for eDNA must carefully assess China, with 25x the US's fishing effort, tremendous needs for coastal restoration, and the potential for outsized influence over everything commercial and marine. Having an analyst

who could read Mandarin and the PRC regulatory tea leaves would greatly benefit a global accounting.

For the **US government as a seed funder**, we draw attention to various agencies' Small Business Innovation Research (SBIR) programs. NOAA (program manager: Genevieve Lind) maintains an SBIR program through which it provides nondilutive (grant) funding to companies, mainly startups, through two laddered phases. Its Phase 1 provides 15 awards yearly out of $4.4mn budget, $175k maximum per award; its Phase 2 provides 18 awards out of a $11.7mn budget, $650k maximum per award. Topics can span any of five areas.

Federal agencies with extramural research budgets over $100 million are required to set-aside 3.2% of their extramural research budget to the SBIR program, and those with extramural research budgets over $1 billion are required to allocate 0.45% to the STTR program. Total NOAA SBIR funding amounts to $16.1mn – perhaps near the minimum 3.2% level (we did find a summary number for NOAA's extramural R&D spend).

Regardless, the maximum grants available from NOAA's SBIR at the Phase 1 and Phase 2 levels are very modest, particularly when compared to other agencies' SBIR maximums, while it is not obvious that the capital requirements in the environmental space would be less than, say medical technology. NIH's Phase 1s max out at $307k, while its Phase 2s max out at $2.05mn. NSF's Phase 1s and Phase 2s max out and $275k and $1mn, respectively.

The cost of developing and deploying the products necessary for eDNA pipelines with trained biologists in the loop may be relatively modest (with citizen/volunteer water collection and filtration, and an underpaid biology labor pool). However, the cost of developing and deploying the products necessary for eDNA pipelines that are fully automated will almost surely not be modest, requiring deft integration of thermocycler and other molecular biology processes, water collection and filtration, and edge computing and communications. This integration will be essential for achieving set-it-and-forget-it usability, and close to real-time information, akin to how weather buoys operate. Perhaps a useful gauge of the

level of investment needed is Saildrone, which has raised some $190mn to launch its fleet of autonomous ocean-going observatories.

This brings us to the private sector, where we first look at eDNA-related companies the SBIR programs of all agencies have funded in recent years (using the search keyword "eDNA" - we are likely missing a few). The Navy's SBIR (program managers Robert L. Smith & Lee Ann Boyer) has more generous maximums at Phase 1 ($270k) and Phase 2 ($1.7mn) levels, and has funded at least three companies in the space versus NOAA's two:

Elder Research (NOAA Phase 1 and Phase 2) PI: Jennifer Schaff

CD3 (NOAA Phase 1 and Phase 2) PI: Ed Rudberg

HJ Science & Technology (Navy Phase 1 and Phase 2) PIs: Erik Jensen & Hong Jiao

Lynntech (Navy Phase 1) PI: Christi Parham

Chromologic (Navy Phase 1) PIs: Dmitriy Zhukov & Naresh Menon

Frontline Biotechnologies, now known as PureBioX (Agriculture Phase 1 and Phase 2) PI: Abdennour Abbas

The Lynntech Navy Phase 1 project may be of special interest – from the abstract: "Traditional methods for assessing biological inhabitants in bodies of water are extremely difficult and have significant logistical burdens. Marine eDNA monitoring may be a very useful tool in greatly reducing these logistical burdens. However, current eDNA monitoring schemes involve sampling various points in a body of water and returning them to laboratories for analysis. Significant advances have been made in the sampling side of marine eDNA collection, such as unmanned underwater vehicles (UUVs) for automated sampling collection, but analysis is still limited to laboratory sites. There is a significant need to bring eDNA monitoring technologies into forward deployment as part of vehicle payloads to simplify the eDNA monitoring process. Lynntech will develop an

innovative eDNA analysis system to couple with deployable vehicles, such as UUVs, to allow for unattended monitoring of marine species. It is the intent of the eDNA analysis technology to provide efficient and accurate biological monitoring of bodies of water."

Using the search keyword "marine," there are other companies developing ancillary technologies:

Blue Ocean Gear (NOAA Phase 1) PI: Kortney Opshaug

Tridentis Advanced Marine Vehicles (NOAA Phase 1) PI: William Latham

Lynntech (NOAA Phase 1 and Phase 2) PI: John Mueller

Marine Advanced Robotics, now part of Ocean Power Technologies (NOAA Phase 1 #1, NOAA Phase 1 #2) PIs: Joshua Mehlman & Mark Gundersen

EQO (eRNA) (NSF Phase 1) PI: John Higley

Mindful of the June 2024 national eDNA conference and interest in the future of the US industry, we strongly recommend engaging with SBIR programs and aggressive effort to engage these small companies as participants, not only as sources of solutions but as sources of information on market sizes and niches.

In the same spirt, we recommend engaging professional investors relevant to eDNA**.** They will have given much more scrutiny to a company's business models and commercial traction (revenues) than SBIR screeners, for example. Professional investors are wagering their own money and that of their limited partners and are looking for a financial return.

Most of the private-sector companies active in eDNA, large and small, are literally private, i.e., not publicly traded or required to disclose their revenues or results of operations. The handful that are public do not report their eDNA work as a distinct segment (akin to NOAA). Thus, our attempt to quantify revenues or market size is frustrated by this opaque state of affairs.

If OSTP/SOST or a new effort wishes to push further on this question, we recommend two tactics. First, we recommend a subscription to the most curated and complete database of private corporate funding and activities, Pitchbook ($12k yearly for one seat). Below we share what we learned from Crunchbase, a far lower cost, far less curated and complete competitor, but we believe that Pitchbook would be worth the pricey subscription.

Second, we recommend direct engagement with the investors who have backed companies in the eDNA space broadly defined. By virtue of being investors, they have been privy to pitches containing internal financial data and projections by company executives, and have implicitly endorsed them, perhaps even developed their own take on or forecast for the sector, and in some cases will have had time to see those projections borne out (or not). After all, commercial eDNA activities have been ongoing for at least nine years (NatureMetrics was founded in 2014; IOGP/IWEB was organized in 2016) so the addressable markets, at least for the offerings that are already on the market, should now be relatively well defined or ground-truthed by the companies themselves.

Investors will likely be more willing and able to speak openly to people representing a USG or academic study than the executives of the companies in their portfolio, who perhaps justifiably fear competitive repercussions from sharing anything without a non-disclosure agreement (NDA) in place.

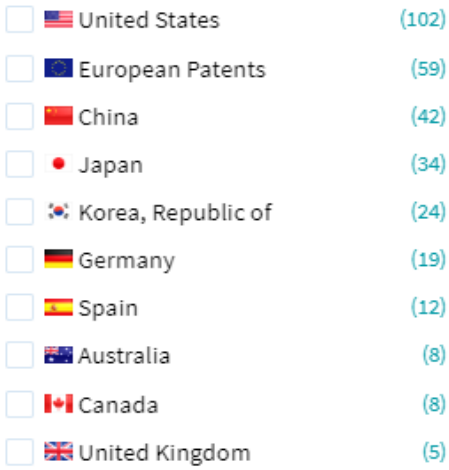
We discovered only one SBIR-funded company that has also received venture investment: Blue Ocean Gear (backers include Signia Venture Partners, Good Growth Capital (Maureen Boyce), BDT & Company, Gratitude Railroad, ImpactAssets, Unpopular Ventures, and Azul Ocean Ventures).

Venturing away from SBIR recipients and looking at the broader picture (often non-US or more mature companies), we find additional investors who have implicitly endorsed some version of the eDNA economy. NatureMetrics, based in the UK (backers include Origin Capital, Acuity Investments, 2150, BNP Paribas Solar Impulse Fund, Systemiq Capital, Ananda Impact Ventures, New Atlantis Ventures, and SWEN Blue Ocean Partners) and Biomeme, based in Philadelphia

(backers include Dreamit Ventures, Robin Hood Ventures, Darco Capital, and angels Andre Needham, Dana Vanwestrienen, David Bolliger, and Ellen Amudipe).

NatureMetrics is private but this site reports an estimated valuation of $79mn on estimated revenues of 6.8mn Euros this year. Its backers have invested over $40mn according to Crunchbase. Given these modest returns, it perhaps shouldn't be surprising that there are relatively few eDNA companies to have attracted private, professional, profit-oriented investors. Watching how NatureMetrics, Biomeme, and Blue Ocean Gear evolve in the years ahead will be instructive. Other names to monitor include Smith-Root, Dartmouth Ocean Technologies, eDNAtec, and Kristy Deiner's SimplexDNA. Perhaps the largest company with eDNA activities is Stantec, a giant NYSE-traded, Edmonton-based consultancy. Stantec is a large, diversified company, so figuring how much business it is doing in eDNA is not possible from the 40F it files with the SEC, which breaks its revenue into only five segments, the most relevant of which is $1.25bn in "environmental services" in 2022. They are currently valued at $8.6bn.

We also recommend using patent databases and other such tools for the information they hold and as a channel to inventors, including those who are corporate-affiliated and may not publish in the academic literature. As an example, we scanned Google Patents and Lens.org, focusing specifically on innovators in thermocyclers (Biomeme: Google Patents & Lens; Inventor: Luke Gary), a key component in the molecular biology piece of the eDNA pipeline, water filtration (Smith-Root: Google Patents & Lens; Inventor: Austen Thomas), and integrated systems with increasing levels of automation (EQO: Google Patents & Lens; Inventor: John Higley). As EQO's patent points out: "Traditional methods of obtaining samples of aqueous media, such as humans filling sample bottles and returning the samples to laboratories for further analysis, are inadequate for generating data on the scale and level of detail to address the challenges of protecting our planet's many and geographically dispersed bodies of water."
A search by the top classification code for Biomeme's patent ("Transportable laboratories; Field kits" CPC: B01l1/52) reveals how a subset of similar patents is distributed geographically:

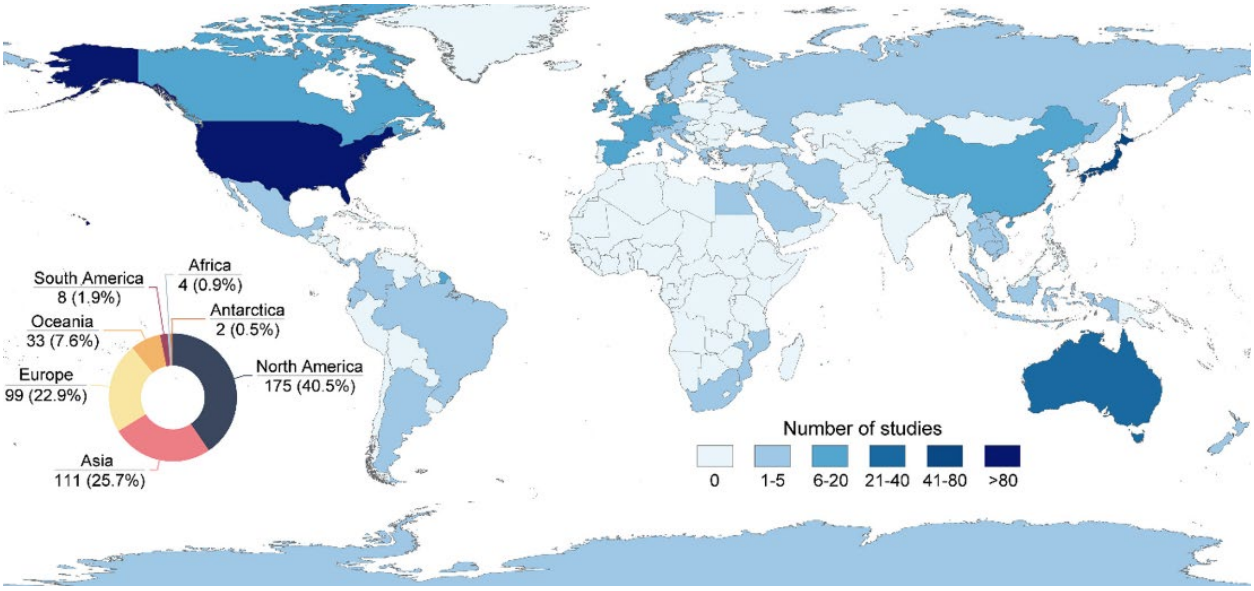


This hierarchy appears fairly consistent regardless of the search terms or filters used. Inventors worldwide aim to access the US market first and foremost. However, as before, this belies the potential influence of China, should they choose to prioritize similar "best practices" or regulations for their domestic EEZ or mainland companies operating internationally.

A thorough update on the status of patents and other facets of intellectual property in regard to eDNA would be a valuable contribution to the June 2024 conference.

As for a back of the envelope estimation of the total number of eDNA samples processed globally, we again recommend thought experiments. For example, we can use the number of papers published in the academic literature (Google Scholar) and apply a liters-sampled-per-paper multiple of nine, which is roughly what our Rockefeller colleague Mark Stoeckle has used in his eDNA work. In 2022 1,890 papers flagged by Google Scholar used the keywords "marine edna" or "environmental dna"; at nine liter-samples per paper, that implies seventeen-thousand samples processed by academic users in 2022

The studies for fish were split geographically along these lines:



Yao, M., Zhang, S., Lu, Q., Chen, X., Zhang, S. Y., Kong, Y., & Zhao, J. (2022). Fishing for fish environmental DNA: Ecological applications, methodological considerations, surveying designs, and ways forward. *Molecular Ecology*, 31(20), 5132-5164.

These snapshots suggest that China and Japan collectively account for a quarter of what we might call eDNA's intellectual market (papers and patents) at present, with the US and Canada between 35-40%.

Other thought experiments could estimate the dollar value of the global eDNA market for goods and services, including software. For example, if we assign 40% of intellectual interest to the US and assume that half of $222mn of NOAA NMFS's survey and stock assessment budget could be spent on eDNA, this would imply a global non-profit-driven fisheries market of about $275mn. The total global market for all applications might be 2 to 10 times this amount, depending on views about needs ranging from aquaculture to windfarms.

Looking at commercial providers by sector, note that the largest players (Stantec, NatureMetrics, Biomeme) are selling hardware devices (kits) and services, often an amalgam of sample collection, molecular biology (qPCR/metabarcoding), and analysis. These services are underpinned by proprietary software, but the vendors (including smaller players like Jonah Ventures) appear content to sell its outputs as

a sort of SaaS (software as a service) with consulting bolted on, instead of selling the software as a standalone product to be used for a customer's own purposes.

Meanwhile, many academic users prefer to rely on their own bespoke software for analysis and visualization. Indeed, for those whose eDNA work includes a teaching component, using software developed by others can be seen as counterproductive corner-cutting if the goal is to develop students' foundational programming skills (in Unix, R, Python, and using HPCC systems).

For those who do wish to use software developed by others, there are a plethora of free options including platforms like QIIME2, Anvio, and R packages like phyloseq, vegan, and ggtree (for phylogenies) [2]. Other popular open-source packages include Phinch and the University of Geneva's SLIM. Even software from commercial vendors like Illumina's bcl2fastq and PacBio's SMRT Tools appears to be furnished for free, designed to work in concert with their sequencing hardware, at least from what we can gather from published papers.

Some use commercial software like Geneious (for which institutions take a site license) but it is not clear how adept Geneious is at handling metabarcoding data. For the actual visualizations, Geneious has some images and tutorial videos on their website (nothing fancy, only basic amplicon analysis). Other not-quite-commercial options would be huge portals like Galaxy or Kbase which are free to use and supported by large computational research groups or national labs.

Geneious (originally NZ-based) is now part of a Boston-based company called Dotmatics (formerly known as Insightful Science). The combined entity is owned by a NYC-based private equity firm called Insight Partners. A press release touts over $100mn in annual recurring revenue across all of their product lines, but we have no way to know how much of that is Geneious, let alone sales of Geneious to eDNA practitioners.

[2] The section on software benefits from expertise of Dr. Holly Bik

Looking ahead, it is useful to be explicit about motives for users to buy eDNA devices or services. For governments and non-profits (including universities), the motives seem to take two forms:

1) knowledge for knowledge's sake – academic research, curiosity, including recreational uses; and
2) knowledge for the sake of establishing regulations (stocks, quotas) or bolstering political aims (activist/ESG shareholder/customer pressure).

In the case of for-profit companies, the motives take two forms:

3) carry out their core business more successfully or efficiently; and
4) comply with and/or satisfy the demands of #2 above.

We recommend that forecasts of possible demand envision scenarios of both carrots (chances for profit) and (sticks) regulatory requirements) that might create demand.

Of those four sources of demand, only #3 could be directly tied to lifting profitability of activities, and that might apply mainly to fishers, and not now but in the future (if the process from water collection all the way to actionable fish information can be both autonomous and in near real time). The other three appear mainly as costs, as a kind of overhead or fee or "tax" to do business. For #1, the example of medical devices is telling: research-use-only devices have tiny markets compared to commercial (revenue producing or enhancing) use, and the same is likely true here. Indeed, the commercial side of the eDNA end-user market appears likely to be driven by a symbiosis between #2 and #4, by executives with titles involving sustainability, stewardship, compliance, and the like, which generally places them outside the more powerful profit corridors of their companies.

For example, NatureMetrics has shared news of its partnership with MSC cruise lines. Upon inspection, the MSC *Foundation* funds the NatureMetrics effort, while the for-profit company is marketing the green credentials of the launch ship. The executive who involved MSC has "responsibility for the sustainability agenda". One worries that the partnership could be dispensed with at an early sign of cruising downturn or disappointing returns from this sort of marketing expense.

Overall, the eDNA market appears to have more to do with sticks than carrots (see the section beginning on page 48 here or this report). A stick business tends to be inherently shakier than those driven by carrots. Thus, forecasts of eDNA demand need to envision the odds of optional "best practices" or new requirements proliferating and spurring demand. Relevant official explicit regulations are currently few, but "best practices" norm-making is underway. The wind industry, now troubled financially in many regions, may be a bellwether.

If the sticks do proliferate, companies such as NatureMetrics are poised to engage. Their list of clients numbers over 500 in 104 countries, according to their website:

However, this impressive wall of logos could be somewhat deceptive: NatureMetrics > 500 customers and €6.8mn in revenues (if dealroom.co's estimate is taken at face value) implies token spending (<€13,600) from each.

As far as making eDNA a more carrot-y proposition, and appealing to commercial or recreational fishers, for example, by making it easier for them to find the fish they are after, eDNA will have to become close to real-time to complement or compete with fish finders, whose technology is not standing still either. Garmin, Lowrance, Humminbird, Simrad, Raymarine, Furuno…all have sonar devices (transducers) that can scan below the boat, laterally some distance, and now display their information as more of a video than a succession of pixelated still images. From traditional sonar to "chirp" sonar and now to "live" sonar, the incumbents are strong and the user experience does not require laboratories or molecular biology. Of course, integrating 'omic and acoustic technology may prove the best path.

In summary, the nascent eDNA market is currently comprised of Federal end-users who could disclose spending but do not yet do so, commercial providers and end-users who are under no obligation to disclose spending on or income from eDNA, and do not, and modest Federal and private investment. Perhaps the best way to

gain greater clarity into the commercial market is to talk with investors who have reviewed the private companies' internal, publicly undisclosed financials, and developed investment theses of their own. The actual totals involved at present are very likely modest, well under half a billion USD globally, as drivers are mostly research-use and optional marketing-driven "best practices," not mandates, at least not yet. In addition, the standardization that might eventually underpin financialization of credits akin to carbon is still a work in progress.

However, the scale and scope of industrialization of the oceans, especially the near-shore and continental shelves, are impressive. Consider the span:
• pumping oil and gas, extracting wind & wave energy, and mining minerals; desalinization;
• shipping goods (including pipelines), information (telecom cables), and people (including illicit);
• building boats, offshore structures (including new islands, barrages), piers and wharves, dredging channels, and reconstructing beaches;
• harvesting living marine wealth, including catching, farming, and processing of fish and other sea life;
• feeding & lodging tourists & visitors and their ships & boats, operating coastal towns and cities; observing and monitoring the oceans for safety, research and prediction;
• disposing of wastes; and
• researching and monitoring.
If marine biodiversity regulations gain teeth, and nice-to-know with regard to environmental impact becomes need-to-know and must-know, then the market niches for eDNA could grow dramatically, given the number of commercial actors with marine (or aquatic) activities that could conceivably become subject to monitoring (the BEA's Blue Economy taxonomy).

In closing, we reiterate opportunities at low cost to obtain additional useful information about eDNA products, services, and firms, in the spectrum of known countries as well as China and Japan, across the range of ocean industries and possible applications. Providing more information about patents and other forms of intellectual property in the eDNA space will also be valuable. Private sector managers and financiers associated with eDNA should participate. An inquiry into

the value and possible growth of the SBIR program with regard to eDNA can help frame public policy questions with regard to growth of commercialization for the US. To move the June 2024 conference to a new level of decision-making, it will be valuable to move quickly to gather and report information accurately about financial, commercial, and economic dimensions of aquatic eDNA, over a span a range of industries and applications.