Integrating Genetic, Genomic and Chemistry Tools into an Improved Management Scheme under the Common Fisheries Policy Remit.

- A contribution to the European Commission Consultation on the Common Fisheries Policy Reform -

The FishPopTrace Consortium

Coordinator: G.R. Carvalho

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Abstract

Scientific advice is undeniably indispensible to sound fisheries management. The reform of the Common Fisheries Policy offers a valuable and timely opportunity of integrating science even more than hitherto into the EU fisheries management scheme, as well as to considerably improve the dialogue between scientists and all other stakeholders. Certainly fisheries science is already taken into account in the process of reaching management decisions, namely through advice provided by ICES, the ACFM and STECF to the EU institutions. However, modern analytical technologies based on genetics, genomics and chemistry used to address marine biological questions including those relevant to fisheries management, still remain almost exclusively harboured by the academic realm. We believe this to be unfortunate, and it stands in stark contrast to the current genetic and genomic technological revolution, which is only paralleled by that in the IT sector. There is significant scope to exploit such advances within the environmental and fisheries context.

We are concerned that a great opportunity might be missed by the European Union to tap into the potential offered by progress made in these fields. That the European Union can assume a pioneering role in the integration of new technologies into fisheries management, has been formerly shown by the successful introduction of satellite-based vessel monitoring systems for control purposes and the effort to include electronic reporting systems. - VMS is nowadays a standard tool of fisheries inspection worldwide.

We believe that the EU has the capacity to play a pioneering role again, by extending genetics, genomics and chemistry into fisheries management. In the following we deploy areas where such modern technologies can be of support along with proposals of how to implement new technologies into a reformed Common Fisheries Policy.

About FishPopTrace: Our consortium consists of 15 research groups, experts in wildlife forensics, stakeholders of the fisheries industry and an external advisor from NOAA, USA. It is funded under the European Union (EU) Seventh Framework Programme (grant agreement n° KBBE-212399) and aims to transfer modern technologies based on genetics, chemistry and forensics into fisheries management to support sustainability and to improve compliance with rules.

More information can be found on: https://fishpoptrace.jrc.ec.europa.eu.

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Definition: **To facilitate the reading of this document we refer in the text mainly to tools based on "molecular and chemical analysis".**

- **Molecular analysis refers to: Tools based on genetics, genomics, transcriptomics/gene expression, and proteomics.**
- **Chemical analysis refers to: Fatty acid analysis and microchemistry (trace elements and isotopes).**

Additional details of the techniques within a fisheries context can be obtained elsewhere[1].

Executive Summary:

In this document the FishPopTrace consortium outlines how modern technologies based on genetics, genomics and chemistry, can contribute to sustainable fisheries under a reformed Common Fisheries Policy. A key premise of these tools is that they can be used in both a *descriptive* fashion, to identify units of biodiversity (*e.g.* species, populations/stocks, farmed fish), and in a *mechanistic* fashion that explore empirically some of the biological (*e.g.* life history, population demography and connectivity) and environmental (*e.g.* oceanic hydrography, environmental stress, climate change, harvesting) factors shaping the distribution and dynamics of such units. Since it is generally agreed that biodiversity across biological levels (population, species, and ecosystem) underpins sustainability and recovery in marine environments, increased awareness and engagement of such tools is recommended strongly. We draw in particular the following conclusions:

1. **The CFP Remit:** On EU level it has been suggested to incorporate the CFP in the context of the Integrated Maritime Policy. Tools based on molecular and chemical analysis can particularly support its environmental pillar, the Maritime Strategy Framework Directive, with respect to its descriptors of "good environmental status".
2. **Aquaculture:** Fish farming plays an ever more important role in the fisheries sector. Both for management of fish farms, and for monitoring and control to avoid negative environmental impacts, molecular and chemical analysis can and should be applied.
3. **Environment and Conservation:** Modern technologies such as DNA analysis, gene expression profiling, and proteomics can be used to monitor environmental status and biodiversity. They can also be used to implement strategies supporting conservation measures.
4. **Climate Change:** The possible perturbation of whole ecosystems, and change in distribution of fish populations poses a major threat to sustainable fisheries. Modern molecular and chemical technologies can help to reveal such changes and be used to develop strategies in order to mitigate their impacts.
5. **Control and Enforcement:** Modern technologies can be used for species identification, even on processed products as well as to determine the geographical origin of fish. They therefore powerfully support traceability schemes as well as control and enforcement, especially when put into a forensic context.
6. **Ecolabelling:** The current extraordinarily swift rise of fisheries certification schemes and ecolabelling can be sustained only when properly monitored by independent control methods. For this purpose molecular and chemical technologies are ideally suited.

[1] MCSW Workshop Minutes and Cadrin. Minutes to the Interdisciplinary Workshop on the Potential and Applicability of Advanced technologies based on Biotechnology, Genetics, Chemistry and Forensics for Traceability and Control in the Fisheries Sector. European Commission DG Mare DG JRC, Brussels, 17 June 2008, and Cadrin, S.X., Friedland, K.D. and Waldman, J.R. Stock Identification Methods: Applications in Fishery Science. Elsevier 1st ed. 2004.

7. **Scientific and Technical Advice**: While scientific and technical advice is central to the CFP and anchored in the EU legislation, we are concerned by the absence of molecular and chemical analysis as components of the advisory framework to the CFP. We therefore suggest to form an advisory expert group to the European Commission, perhaps under the remit of already existing advisory bodies.

8. **Management:** Molecular and chemical technologies can help to identify fish populations and stocks and to define management units, including application to "mixed-stock" analysis. The same technologies can also be used to monitor the size, dynamics and distribution of stocks. Generally we note a striking discrepancy between the extent to which genetics is applied in the marine realm for management purposes, as compared to terrestrial wildlife management and ecology, where the integration of population genetics is commonplace. The reasons for this are certainly not to be found in any particular obstacles entailed by the oceanic environment, which is exemplified by the accumulating number of examples for the successful application of modern molecular analytical technologies, for issues also relevant to fisheries management.

9. **Steps towards the integration of genetics and chemistry into fisheries management under the CFP remit:** The successful transfer of modern technologies tools based on molecular and chemical analysis into the CFP scheme will depend on major efforts put into capacity building. For this purpose a much more intense dialogue among stakeholders is required and also the creation of an effective data infrastructure facilitating access to data and leading to improved coherence.

10. **Costs & Benefits:** The assessment of costs and benefits of developed strategies and technologies for fisheries MCS and traceability is necessary to provide a valuable reference for policy analysts and other stakeholders. Examples of where such technologies are in use for fisheries management and control purposes along with the current exponential drop in DNA sequencing costs strongly hint a high benefit to cost ratio for molecular and chemical technologies for fisheries management.

11. **The current document presents a concise compendium of benefits arising from the integration of modern analytical technologies based on genetics, genomics and chemistry within a reformed CFP. We are committed to engage proactively with stakeholders and appreciate further questions and suggestions. For any request please contact Prof. Gary Carvalho (g.r.carvalho@bangor.ac.uk), coordinator of FishPopTrace and Chairman of the European Fish Barcoding of Life Initiative.**

In the introduction to its Green Paper on the reform of the CFP the European Commission draws up a vision for European fisheries by 2020, which describes a rather utopian world where basically all present problems have been resolved and the fisheries sector is thriving and in harmony with nature. In reality, achievement of such a vision will rely on major efforts from all stakeholders, and we believe that the integration of modern tools based on molecular and chemical analysis into the CFP can contribute substantially to this endeavour. This is illustrated in the following by addressing some of the most prominent issues plaguing the fisheries sector of the European Union.

The Common Fisheries Policy remit

The CFP, as the European Union's principle instrument for the management of fisheries and aquaculture[2], aims at assuring the sustainable exploitation of fish stocks and fish farms in a healthy marine environment and a prosperous EU-wide socioeconomic setting. With most of the stocks in Community waters exploited far above the maximum sustainable yields, however, these aims are not met. In its Green Paper the European Commission suggests to move away from the concept of looking at the fisheries sector as an isolated entity and to put the CFP in the context of the Integrated Maritime Policy (IMP)[3], particularly its environmental pillar, the Maritime Strategy Framework Directive (MSFD)[4]. We fully endorse such a notion and believe that modern state of the art molecular and chemical technologies, if properly implemented, can constitute an invaluable asset to a more holistic approach to fisheries management.

For example according to the MSFD, by 2021 the EU Member States are obliged to ensure the good environmental status of the seas under their jurisdiction, and more specifically in Article 9 it is stated that, "*...Member States shall, in respect of each marine region or subregion concerned, determine, for the marine waters, a set of characteristics for good environmental status, on the basis of qualitative descriptors…*" such as:

1) Maintenance of biological diversity;
2) Introduction of non-indigenous species, introduced by human activities are at levels that do not adversely alter the ecosystems;
3) Populations of commercially exploited fish and shellfish are kept within safe biological limits;
4) All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.

To all four listed points the application of modern molecular and chemical technologies could efficiently contribute, for example for monitoring purposes, as shown by many scientific publications.

Aquaculture

Aquaculture is often regarded as a panacea to protect wild fish and shellfish from overexploitation, and according to the FAO, after growing steadily, in 2009 aquaculture contributed for the first time half of the fish consumed by the human population worldwide with marine aquaculture accounting for 34 percent of production and 36 percent of total value[5]. Aquaculture contributes over 18% of the EU fish production and even though it represents only 2% of the world aquaculture production, farming of marine (and anadromous) fish like salmon, sea bass and sea bream continues to grow[6].

Unless closely monitored, however, aquaculture might well turn out to be a peril rather than a blessing: Fish farming operations have significant impacts on aquatic systems, many of which can contribute to the decline in ocean health. There are indeed numerous challenges arising through the increase of the fish farming activity, such as finding a sustainable and environmentally friendly way to feed farmed fish. Other issues are the introduction of pathogens and parasites, which threaten the

[2] Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy.
[3] The Blue Book (An Integrated Maritime Policy (IMP) for the European Union (COM(2007) 575)).
[4] Maritime Strategy Framework Directive (Directive 2008/56/EC of the European parliament and the Council of 17 June 2008 establishing the framework for Community action in field of marine environmental policy; OJL 164, 25.06.2008)
[5] FAO Fisheries and Aquaculture Department (2009) THE STATE OF WORLD FISHERIES AND AQUACULTURE 2008.
[6] 1. European Commission (2009) The common fisheries policy: A user's guide. Fact Sheet: Aquaculture.

farms themselves as well as wild fish in the surrounding environment. Wild fish populations are however also endangered by farm escapees as those might reproduce with their wild counterparts and lower the overall fitness[7]. Such effects might occur through the reduction of genetic diversity of wild populations, since aquaculture is genetically speaking "monoculture", or the introduction of new alleles or, especially in the case of genetically modified fish, even of new genes[8]. The threat of genetic introgression by farm escapees has generally been recognized and in many countries there are laws in place holding the fish farm owners liable for escaped fish. Nevertheless, there remains a need to monitor farm escapees in relation to legislation. Related to this are re-stocking or stock enhancement approaches, where fish bred in captivity are often used. Such "alternative management" measures need careful consideration and should take into account possible genetic impacts[9].

Modern technologies such as DNA analysis, but also others like fatty acid analysis or gene expression profiling can provide the following support to aquaculture management and monitoring:

- Establishment of sound breeding strategies;
- Monitoring of health status of aquaculture fish and detection/identification of pathogens;
- Detection of farm escapees and assignment of escaped fish to the farm of origin;
- Development of re-stocking strategies and post-release monitoring.

These issues were already successfully addressed in projects like the FP6 funded Genimpact[10]. Recent publications show the tractability of addressing the challenging, yet for control and law enforcement indispensible, issue of farm escapees detection and assignment to the farm of origin[11].

Environment, Conservation & Biodiversity

Fishing does not only affect the targeted stocks but has also a significant impact on the environment and whole ecosystems[12]. Therefore, in order to move towards sustainability, fisheries cannot be managed as "standalone activities". Such an integrative rationale was already acknowledged in the 2002 Regulation of the CFP, by emphasizing the importance of conservation, and by aiming at a progressive implementation of an ecosystem-based approach to fisheries management (EBFM)[13].

EBFM has to be coherent with the Maritime Strategy Framework Directive (see above) and the Habitats Directive[14], which constitutes the legal basis for establishing a Europe-wide network of protected areas (Natura 2000), including a network of marine protected areas (MPAs). One crucial element to these approaches is the monitoring and maintenance of biodiversity[15]. – In the context of this document it is noteworthy that the International Union for Conservation of Nature (IUCN)

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[7] McGinnity, P., Prodöhl, P., Ferguson, A., Hynes, R., Maoiléidigh, N.Ó., Baker, N., Cotter, D., O'Hea, B., Cooke, D., Rogan, G., Taggart, J., Cross, T. Fitness reduction and potential extinction of wild populations of Atlantic salmon, Salmo salar, as a result of interactions with escaped farm salmon (2003) Proceedings of the Royal Society B: Biological Sciences, 270 (1532): 2443-2450.

[8] Zbikowska, H.M. Fish can be first - Advances in fish transgenesis for commercial applications (2003) Transgenic Research, 12 (4), pp. 379-389.

[9] Se *e.g.* ICES, 2008b. Report of the ICES Advisory Committee on Fishery Management, Advisory Committee on the Marine Environment and Advisory Committee on Ecosystems, Book 8: The Baltic Sea. 8.3.3.1 Advice on a project concerning restocking of cod in the Western Baltic.
(SOURCE: http://www.fishsource.org/fishery/atlantic%20cod%20-%20baltic%20sea%20%28western%20stock%29/sources)

[10] Svåsand T, Crosetti D, Garcia-Vàzquez E, Verspoor E (eds) (2007) GENIMPACT: Genetic Impact of aquaculture activities on native populations. Final scientific report (FP6 EU contract n. RICA-CT-2005-022802).

[11] *e.g.* **a**. Adey EA, Black KD, Sawyer T, Shimmield TM & Trueman CN (2009) Scale microchemistry as a tool to investigate the origin of wild and farmed *Salmo salar*. Mar Ecol Prog Ser 390: 225-235.
b. Glover KA, Skilbrei OT & Skaala Ø (2008) Genetic assignment identifies farm of origin for atlantic salmon *Salmo salar* escapees in a norwegian fjord. ICES J Mar Sci 65: 912-920.
c. Sérot T, Gandemer G & Demaimay M (1998) Lipid and fatty acid compositions of muscle from farmed and wild adult turbot. Aquac Int 6: 331-343.

[12] See *e.g.* Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions of 17 October 2007 on destructive fishing practices in the high seas and the protection of vulnerable deep sea ecosystems [COM(2007) 604 final].

[13] Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy. Article 2. Official Journal of the European Communities L 358, 31.12.2002, 59-80.

[14] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal L 206, 22/07/1992: 7-50.

[15] Commission Communication of 22 May 2006 "Halting the loss of biodiversity by 2010 - and beyond - Sustaining ecosystem services for human well-being" [COM(2006) 216 final] and Commission Communication of 27 March 2001 to the Council and the European Parliament: Biodiversity Action Plan for Fisheries (Volume IV). [COM(2001) 162 final].

recognizes genes as one of the three primary levels of biodiversity (along with species and ecosystems).

Modern technologies such as DNA analysis, gene expression profiling, and proteomics can support the CFP in the context of the above mentioned aspects tremendously. It could for example be envisaged to use these technologies for placing and designing MPAs, based on the levels and distribution of genetic diversity for areas under consideration, thereby optimizing biodiversity protection. Moreover, once created, the same technologies can be used to monitor MPAs to determine the genetic diversity of residential populations or help surveying the species composition of communities, as well as comparison of intra- and extra MPA monitoring activities to assess the effect of MPAs on ecosystems.

Also questions related to population (stock) sizes can be addressed: It is generally assumed that marine fish have very large population sizes, but recent evidence based on population genetic analyses have shown that this might be an over-simplified and treacherous perception: A number of genetic studies on commercially exploited species such as cod, plaice and striped bass demonstrated the effective population size, *i.e.* (put simplistically) the number of reproducing individuals within a population, can be orders of magnitude smaller than the consensus size (the total number of individuals of a population)[16]. A closely related issue is the extent and dynamics of connectivity between fish populations and/or stocks, which is determined by effective migration, loosely speaking the movement of individuals from one distinct population to another, thereby introducing new alleles of genes (a process called "gene flow"). Effective migration is correlated to the effective population size and can be determined by population genetic approaches. Both effective population size and connectivity between populations have important implications for fisheries management and conservation measures in terms of adaptability to environmental change, and should be taken into account.

A great opportunity to facilitate and optimize the integration of any of the aforementioned technologies into a holistic and ecosystem-based approach for fisheries management and conservation arises with the combination of geographical seascape features and molecular marker analysis. Such an approach allows understanding of the interplay between environmental factors and fish populations. Similar to terrestrial systems, oceans are in fact highly structured by the seafloor shape, currents, gyres, eddies, temperature but also chemical parameters such as salinity. Combining such physical and chemical with genetic and other biological parameters in statistical analysis, not only allows the determination of factors shaping population patterns of marine organisms, but also the monitoring of changes. This approach has recently been successfully employed in several studies on marine mammals, but also Atlantic cod and herring[17], and can help to define management units or create MPAs[18].

Of course the design of fisheries management units or MPAs depends on the involvement of stakeholders such as fisheries managers and policy makers. A fruitful collaboration between scientific and non-scientific stakeholders can greatly be boosted by integrating such combined analyses into Geographical Information System (GIS) based applications. Such an approach is for example followed by Marine Map, a web-based decision support tool for marine spatial planning (www.marinemap.org), and also specifically adapted to the context of genetics and chemistry by FishPopTrace.

Climate Change

The 2009 issue of the FAO report on the State of World Fisheries and Aquaculture emphasises in its foreword that both genetic resources and climate change may receive increasing attention in fisheries and aquaculture , and in fact both aspects are strongly correlated. The report points out that climate change threatens sustainable fisheries at several levels. Global warming, and the resulting changes in physical properties of the oceans, will most probably have far-reaching consequences for marine biodiversity, such as habitat changes and ecosystem shifts. Marine fish may respond to these

[16] Reviewed in Hauser L & Carvalho GR (2008) Paradigm shifts in marine fisheries genetics: Ugly hypotheses slain by beautiful facts. Fish Fisheries 9: 333-362.
[17] Reviewed in Hansen, M.M., Hemmer-Hansen, J. (2007) Landscape genetics goes to sea. Journal of Biology, 6 (3): 1-3.
[18] Reiss, H, Hoarau, G, Dickey-Collas, M & Wolff, WJ (2009) Genetic population structure of marine fish: mismatch between biological and fisheries management units. Fish and Fisheries, 10 (4): 361-395.

environmental changes by altering their distribution and/or by adapting to the new conditions. The latter, if heritable, *i.e.* through Darwinian evolution, might well be irreversible, and affect crucial biological parameters for fisheries, such as productivity. The fisheries sector, and its socio-economic structure, might be severely affected by these developments. Thus, the Green Paper on the reform of the CFP stresses the importance of incorporating knowledge of the effects of climate change into future fisheries management. Due to the complexity of climate change effects, the ultimate consequences remain currently highly unpredictable. However, genetic and genomic methods are crucial tools for advancing our understanding of the responses of organisms and populations to changing climatic conditions[19]. Furthermore, monitoring of fish populations and usage of genetic data together with physical and chemical parameters of the oceans (see also seascape approaches above) for modelling purposes will help to assess past and current state of fish stocks and allow projections of future responses to predicted environmental changes. Foremost among the key advances that the new molecular technologies allow is the assessment of the genetic component of intra- and inter-population diversity in response to change, and the identification of key genes underlying the adaptive shifts that allow population persistence and recovery. Since adaptive change necessarily requires appropriate genetic diversity of ecological traits, the use of tools to identify and monitor genes in time and space is a fundamental component of our predictive capacity. The generation of such predictive frameworks can underpin fisheries management considerations in order to develop strategies to counteract possible adverse effects of climate change for fisheries.

Control & Enforcement: Developing a culture of Compliance

Improving the CFP control scheme through the use of modern molecular and chemical technologies, within a forensic framework has already been considered by the FishPopTrace consortium in a document submitted to the European Commission in the context of the CFP control reform proposal consultation[20]. It is noteworthy that in the CFP control reform proposal[21] new technologies such as traceability tools based on genetics, are explicitly mentioned and further elaborated in the accompanying impact assessment[22]. We hope that these elements will be retained, and potentially extended, in the final version of the future control regulation.

However it is worth pointing out that such technologies can provide invaluable support as independent control methods in the context of the measures envisioned to fight Illegal, Unreported and Unregulated (IUU) fishing as laid down in the soon to be implemented IUU Regulation[23], specifically with regards to the foreseen catch certificate. As discussed in our consultation contribution, mentioned above, genetics and chemistry can be used for species identification, even on processed products, as well as revealing the geographical origin of fish. This is particularly valuable for fisheries control and enforcement when integrated into a forensic framework[24], an approach followed by FishPopTrace. While species identification using molecular tools is well established, it is in relatively recent times that high-throughput and globally accessible databases have become operative, such as the Consortium for the Barcode of Life, Fish DNA barcoding campaign, FISH-BOL (http://www.fishbol.org). Ascertaining geographic or spawning group identity of fish is more challenging, though advances in molecular and chemical approaches allow the detection of population-level signatures across increasingly fine scales. Moreover, such tools can be validated forensically to ensure reliability and robustness within the legal context required for prosecution and enforcement.

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[19] Reusch, T.B.H., Wood, T.E. Molecular ecology of global change (2007) Molecular Ecology, 16 (19): 3973-3992.

[20] http://ec.europa.eu/fisheries/cfp/governance/consultations/consultation_280208_en.htm; see Contributions received: "*The Potential and Applicability of Modern technologies based on Biotechnology, Genetics, Chemistry and Forensics for Fisheries Control.*", The FishPopTrace Consortium (2008).

[21] Commission of the European Communities: Proposal for a Council Regulation establishing a Community control system for ensuring compliance with the rules of the Common Fisheries Policy. Brussels, COM(2008) 721 final.

[22] Commission of the European Communities: Commission Staff Working Document accompanying the Proposal for a Council Regulation establishing a Community control system for ensuring compliance with the rules of the Common Fisheries Policy - Impact Assessment. Brussels, SEC(2008)2760/2.

[23] COUNCIL REGULATION (EC) No 1005/2008 of 29 September 2008 establishing a Community system to prevent, deter and eliminate illegal, unreported and unregulated fishing, amending Regulations (EEC) No 2847/93, (EC) No 1936/2001 and (EC) No 601/2004 and repealing Regulations (EC) No 1093/94 and (EC) No 1447/1999. Official Journal of the European Union L 286, 29.10.2008: 1-32.

[24] Ogden, R. (2008) Fisheries forensics: the use of DNA tools for improving compliance, traceability and enforcement in the fishing industry. Fish Fisheries 9: 462-472.

Specific mentioning deserves in this context the EU action plan for the conservation and management of sharks[25], since it is a prominent Commission initiative. This recent and ambitious action plan is formulated in concordance with the FAO International Plan of action for the conservation and management of sharks (IPOA Sharks; 1999). The plan includes measures intended to improve data collection and scientific advice, management and technical measures and a further strengthening of the application of the shark finning ban[26].

Recently in the USA DNA tests, developed by the Nova Southeastern University in Florida, were used to uncover and prosecute illegal shark fin traders in the USA. NOAA law enforcement agents confiscated about one ton of dried shark fins that a seafood dealer was planning to ship to Asian markets under false labels. The tests positively identified fins that came from seven different prohibited species. The suspect later agreed to a settlement of $750,000 in the case, in great part due to the strength of the DNA evidence, as stressed by the NOAA law enforcement department which also pointed out the speed with which enforcement officers can get results[27]. It should generally be pointed out that especially evidence based on genetic forensics is shown to have a strong deterrent effect and could therefore constitute a highly valuable element in the attempt to boost fairness and top create a culture of compliance in the fisheries sector.

Even origin assignment of fish, enabled by genetic, has found its way into European courts: In Denmark a fisherman was convicted, based on DNA evidence, for having sold North Sea cod as Baltic cod. The catch was confiscated and the fisherman had to pay a substantial fine[28]. However, despite such “success examples” an EU-wide coherent approach to fully integrate modern molecular technologies into fisheries monitoring, control, surveillance (MCS) and enforcement as well as into a traceability scheme covering the supply chain (from “ocean to fork”) is lacking. It is the ambition of FishPopTrace to support such an approach by developing forensic tools for origin assignment, based on modern molecular and chemical technologies, and to help catalysing a technology transfer into the CFP control scheme.

To begin with we recommend the establishment of a trans-border network of certified laboratories. Such a network can build on already available expertise, *i.e.* the creation of new laboratories is probably not necessary. It would support national authorities in all EU member countries, and eventually beyond. Such an EU-wide approach could also increase the cost efficiency substantially.

That forensic genetics and chemistry are already employed worldwide and under consideration as valuable for fisheries control and enforcement is also shown by a recently held FAO workshop on this subject, assembling international experts in the field as well as other stakeholders[29].

Ecolabelling

Certificates attesting that fish products derive from sustainably exploited stocks, and more generally eco-labelling schemes, assuring consumers that a product has been produced according to defined environmental standards, gain quickly popularity in the fisheries sector. This has prompted the European Commission to launch a debate on a Community approach towards eco-labelling schemes for fisheries products[30]. Probably the most common of such certificate schemes is currently that of the global non-profit organisation Marine Stewardship Council (MSC), which has been operating since 1999[31]. Many EU fisheries meanwhile attempt to obtain this certificate. - One of the latest and most impressive examples is certainly Denmark, the world's fifth largest seafood exporter by value, where the Fishermen's Association (DFA) is aiming to have the entire Danish fisheries certified as sustainable under the MSC eco-labelling scheme before the end of 2012. Meanwhile there

[25] Communication from the Commission to the European Parliament and the Council of 5 February 2009 on a European Community Action Plan for the Conservation and Management of Sharks [COM(2009) 40 final].

[26] Council Regulation (EC) No 1185/2003 of 26 June 2003 on the removal of fins of sharks on board vessels
Official Journal L 167, 4.7.2003: 1–3.

[27] This example is part of a collection of similar cases where (forensic) DNA analysis was used in fisheries control and enforcement, delivered in 2009 to DG Mare by DG JRC.

[28] Personal communication: L.B. Erikson (Danish Directorate of Fisheries; Inspectorate of Fisheries); E.E. Nielsen (Technical University of Denmark); and see footnote 27.

[29] FAO Informal; Workshop on the Use of Forensic Technologies in Fisheries Monitoring, Control and Surveillance. FAO Headquarters, Rome, Italy. 9 - 10 December 2009.

[30] Communication from the Commission to the Council, the European Parliament and the European Economic and Social Committee: Launching a debate on a Community approach towards eco-labelling schemes for fisheries products. [SEC(2005)840].

[31] http://www.msc.org/

are more than 50 MSC approved fisheries worldwide, jointly producing over 5 million tonnes of seafood (about 7% of the world's edible wild captures), and 100 fisheries are under assessment, clearly illustrating the dynamic development in this area. Recently the FAO has developed guidelines for eco-labelling schemes, which have been endorsed by its members, to which the European Communities belong.

A holistic approach to fisheries management, based also molecular and chemical state-of-the-art technologies would firstly support sustainable fisheries, the primary requirement to obtain an eco-label. Moreover such technologies would be an asset in the endeavour to monitor certified fisheries as to guarantee the required criteria remain fulfilled.

In the following we wish to illustrate how modern molecular technologies can support the CFP as well from top-down, through the support of law-enforcement, as through assisting consumer choice: To EU citizens the CFP regulatory framework appears as highly complex and difficult to comprehend. Perhaps, at least partly, this complexity, caused by a high number of very specific regulations, opens margins to circumvent the law. Indeed, according to the court of auditors the culture of compliance under the CFP is vastly underdeveloped and control as well as enforcement proved to be largely ineffective.

In a top-down approach to counteract this tendency new laws are introduced such as the IUU regulation, and as we discussed above, modern technologies based on genetics, genomics and chemistry can help in their implementation. On the other hand a very strong incentive for the fishing industry to improve fisheries management schemes emerges from the consumers, which exercise their choice which is biased towards sustainably and legally exploited fish. Indeed at least theoretically a positive feedback mechanism could emerge, since consumers would apply certain criteria when buying fish (products), which the suppliers would try to satisfy. This is an opportunity and a peril at the same time: It is difficult to see how, at the current speed with which certification applications are submitted and authorizations delivered, the well-intended aims of such schemes can be reached in the long run. Unless carefully monitored there is a substantial danger that eco-labelling schemes begin to fail. Also the risk of emerging free riders, using falsified labels is considerable. This would ultimately damage credibility and undermine consumer faith. Properly applied, the approaches followed by such initiatives as FishPopTrace can support the control for adherence to eco-labelling schemes, and our consortium has been contacted by the Marine Stewardship Council to be advised on this issue.

Scientific and Technical Advice (and the Conspicuous Absence of Genetics)

The importance of scientific advice to good fisheries management has been stressed in the CFP Regulation of 2002[32] and further emphasized in a communication by the European Commission on improving scientific and technical advice for Community fisheries management[33]. Particularly article 2 of the CFP Regulation ("Objectives") lays down that the Common Fisheries Policy shall be guided by a variety of good governance principles amongst which "*a decision-making process based on sound scientific advice which delivers timely results*".

The main advisory bodies to the European Commission are the International Council for the Exploration of the Sea (ICES) and the permanent Commission internal Scientific, Technical and Economic Committee for Fisheries (STECF)[34]. In the decision establishing STECF it is stressed that "*the implementation of Community policy for fisheries and aquaculture requires the assistance of highly qualified scientific personnel, particularly in the application of marine and fisheries biology, fishing technology, fisheries economics or similar disciplines, or in connection with the requirements of research and data collection in the fields of fishing and aquaculture*".

It is striking to observe that despite this strong endorsement of scientific advice, as a valuable component of fisheries management under the CFP remit, expert advice on modern technologies based on molecular or chemical analysis remain vastly absent. This is indeed also in stark contrast to the ongoing revolution in molecular genetics and genomics, both fields which definitely have been

[32] Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy. Article 2. Official Journal of the European Communities L 358, 31.12.2002, 59-80.

[33] Commission communication of 23 December 2002 on improving scientific and technical advice for Community fisheries management. Official Journal of the European Union C 47, 27.02.2003, 5-16.

[34] Commission Decision of 26 August 2005 establishing a Scientific, Technical and Economic Committee for Fisheries (2005/629/EC).

incorporated effectively into wildlife management and also fisheries science as shown by numerous scientific publications. Interestingly advisory expert groups covering these areas do exist. An example is the ICES Working Group for Applied Genetics in Fisheries and Mariculture (WGAGFM), a panel of internationally renowned scientists gathering every year to formulate high-level expert advice for fisheries management based on genetics and genomics. This advice is posted on the ICES website but hardly ever taken seriously into consideration for policy decisions or concrete management approaches. There exist a variety of reasons for this gap between science in this area and policy making, but a major driver causing the current reciprocal non-awareness is a lack of dialogue between all stakeholders concerned, and the misapprehension that "genetics" is concerned with only evolutionary change over geological time scales. It is becoming increasingly clear that genetic change in fish, as in other taxa, can occur across extremely short time scales[35] , generating the need for effective monitoring and implementation of such methods and concepts into routine management of fish resources.

We feel a great opportunity is missed here and suggest bridging this gap by forming an advisory expert group to the European Commission, perhaps under the remit of already existing advisory bodies. We would at this point also like to stress that with "providing advice" we do not mean to counsel the Commission exclusively in very generally terms on the subject. In contrast, concrete questions can be addressed with respect to specific species and distinct stocks or the resolution of specific issues, such as supporting an efficient traceability scheme (see also below - "Management").

Management

At the core of the legislation currently underpinning the CFP it is stated that "*the Common Fisheries Policy shall ensure exploitation of living aquatic resources that provides sustainable economic, environmental and social conditions*."[36]. Quite obviously to reach these objectives ways have to be found to move towards fish stocks that are productive in the long run and, -indivisibly linked to that -, embedded in healthy marine ecosystems.

We outlined above that molecular and chemical technologies can greatly assist these goals. Meanwhile data arising from molecular genetics or chemical studies on marine fish, can be used to address many aspects invaluable to sound fisheries management: population identification, species identification and composition, genetic diversity and fitness and changes thereof over time in relation to environmental changes (*e.g.* global warming) or in response to direct anthropogenic influence (*e.g.* fishing pressure). Yet, the integration of such data into EU fisheries management or into considerations for the setting of the CFP framework remains at most marginal.

In fisheries management the term "stock" refers normally to an exploited demographic entity of one species. However to identify demographically independent populations which can be modelled separately, *e.g.* for stock assessment methods, is a challenge[37]. Genetics can help to identify fish populations/stocks ("Genetic Stock Identification" or GSI), and to define management units. This has meanwhile been applied for a number of marine fish. Even one of the most challenging questions in fisheries management, namely that of "mixed-stock" analysis, even in marine fish[38], can be addressed with GSI approaches as discussed in a recent review by Waples et *al*.[39]. At the same time however the authors point out that for several reasons, historical and communication related, such data has not yet been largely integrated into management schemes. The authors also raise the possibility that the endeavour to resolve mixtures can be in vain due to the limits of resolution power for very close populations. However even such a result should influence management decision (application of a precautionary approach rather than simply treating the examined population as one stock). Moreover

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[35] Hauser, L. and Carvalho, G.R. (2008) Paradigm shifts in marine fisheries genetics: ugly hypotheses slain by beautiful facts Fish & Fisheries 9: 333-362.
[36] Council Regulation (EC) No 2371/2002 of 20 December 2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy. Article 2. Official Journal of the European Communities L 358, 31.12.2002, 59-80.
[37] Waples, R.S., Punt, A.E., and Cope, J.M. (2008) Integrating genetic data into management of marine resources: how can we do it better? Fish & Fisheries 9: 423-449.
[38] Ruzzante, D.E. et al. Biocomplexity in a highly migratory pelagic marine fish, Atlantic herring (2006) Proc.Biol.Sci. 273 (1593): 1459-1464.
[39] Waples, R.S., Punt, A.E., and Cope, J.M. (2008) Integrating genetic data into management of marine resources: how can we do it better? Fish & Fisheries 9: 423-449.

the resolution power can often be improved by using alternative genetic markers or by increasing the number of a specific genetic marker type.

Microchemistry and isotope analysis on hard tissues such as otoliths, fish bones, but also muscle tissue can be applied to clarify he demographical interdependence between exploited stocks. This has recently been shown for Bluefin Tuna (*Thunnus thynnus*), where otolith microchemistry has been used to examine the degree of relatedness of the Atlantic and Mediterranean stocks[40]. In another highly elaborate study on pink ling (*Genypterus blacodes*) in New Zealand it was shown that trace element analysis on muscle tissue can be used to distinguish groupings of fish of different areas. This is distinct from a genetic approach in that exclusively demographic relationships are revealed instead of reproductive relatedness. However, both approaches can complement each other, provide independent levels of evidence, and assist fisheries management on several levels, including control and enforcement as questions related to origin assignment of fish can be answered[41].

Another important aspect is long term impact on fish stocks caused by fishing. Evidence is accumulating that fishing pressure acts as a strong selective agent, and lead to (potentially irreversible) adaptations of heritable traits (fisheries induced evolution). An evident (yet oversimplified) example is the decline in average size of fish facilitating the escape through the meshes of nets. This subject is addressed by the ICES Working Group on Fisheries Induced evolution (WGEVO) as well as the European research network FinE (http://www.iiasa.ac.at/Research/EEP/FinE), which will also submit a contribution to the CFP reform consultation. Genetics and genomics can help to identify and monitor such processes and support efforts to develop strategies for long-term sustainable exploitation of fish stocks, and thereby minimise the risk of detrimental effects.

The technologies we discuss here can help to support short and medium term management strategies, such as the above mentioned re-stocking or stock enhancement (see ‘Aquaculture’). However they are also highly valuable to create a long-term perspective for management decisions: Access to historic tissue samples of fish and the capability to analyse them on a molecular level[42], enable us to throw a look back into the history of stocks, as well as to compare the data with environmental parameters along the same historical trajectory. This in turn helps to understand the dynamics of stocks and to optimize long-term management approaches.

Generally molecular technologies have repeatedly shown to be valuable for fisheries management. For example the analysis of ichtyoplankton, notoriously difficult by visual inspection, performed with DNA technology revealed a probable overestimation of the cod stock in the Irish Sea[43]. Also a study based on genetics, morphology and life history that was just published revealed that two distinct species have been erroneously confused as European common skate (*Dipturus batis*)[44]. This finding puts into question all previously accumulated data based on *D. batis*, and has major consequences for the management of this species, especially in view of its endangered status. It also stresses the great value that the International Fish Barcoding of Life Initiative (FISH-BOL[45]) has, where a standardised reference DNA sequence library for all fish species is currently assembled, which can tremendously help to clarify taxonomic ambiguities.

Generally we note a striking discrepancy between the extent to which genetics is applied in the marine realm for management purposes, as compared to terrestrial wildlife management and ecology, where the integration of population genetics is commonplace. The reasons for this are certainly not to be found in any particular obstacles entailed by the oceanic environment. This is also exemplified by an accumulating number of examples for the successful application of modern molecular analytical technologies, with value for fisheries management.

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[40] Rooker, J.R., Secor, D.H., De Metrio, G., Schloesser, R., Block, B.A., Neilson, J.D. Natal Homing and Connectivity in Atlantic Bluefin Tuna Populations (2008) Science 322 (5902): 742-744.

[41] Graeme Bremner, Ministry of Fisheries, Dunedin, New Zealand: Personal communication.

[42] Nielsen, E.E., Hemmer-Hansen, J., Larsen, P.F., Bekkevold, D. Population genomics of marine fishes: Identifying adaptive variation in space and time (2009) Molecular Ecology, 18 (15): 3128-3150.

[43] Fox, C.J., Taylor, M.I., Pereyra, R., Villasana, M.I., Rico, C. TaqMan DNA technology confirms likely overestimation of cod (*Gadus morhua L.*) egg abundance in the Irish Sea: Implications for the assessment of the cod stock and mapping of spawning areas using egg-based methods (2005) Molecular Ecology, 14 (3): 879-884.

[44] Iglésias,S.P., Toulhoat, L., Sellos, D.Y. (2009) Taxonomic confusion and market mislabelling of threatened skates: important consequences for their conservation status. Aquatic Conserv: Mar. Freshw. Ecosyst. DOI: 10.1002/aqc.1083.

[45] http://www.fishbol.org/

Costs & Benefits

In the context of its aim to catalyse a technology transfer, FishPopTrace fully acknowledges the importance of estimating costs and benefits of developed strategies and technologies for fisheries MCS and traceability to provide a valuable reference for policy analysts and other stakeholders.

However it is important to note that there are already strong indications that the methods discussed here are highly cost effective, and provide great benefits. To these indicators belong examples where such technologies are in use for fisheries management (*e.g.* Canadian salmon) or for enforcement purposes (see above). Moreover especially DNA-based applications and analysis benefit from an exponential drop in sequencing costs, accompanied by an enormous increase in analytical power as exemplified by the current frequency of newly published whole individual human and vertebrate genome sequences.

Also the fisheries sector could greatly benefit from this trend. FishPopTrace has achieved within a short time to generate for hake, herring and common sole over 100 million bases of sequence data from which approximately 7500 candidate SNP markers per species were discovered which are currently assessed with respect to population identification power.

Steps towards the full integration of molecular and chemical analysis into fisheries management under the CFP remit

We addressed above issues and challenges central to the Common Fisheries Policy, and explained how molecular and chemical technologies can contribute to an improved Community fisheries management. However in our opinion several initiatives will have to be taken and some conditions to be improved, to assure that these technologies can be fully transferred into fisheries management schemes.

It is certainly crucial to further enhance the dialogue between European policy makers and scientists working in the field of molecular and chemical technologies. This would on the one hand allow experts in the field to better comprehend the challenges and issues inherent to the CFP, and on the other, raise awareness amongst policy makers about the potential and limits of modern technologies. Examples for successful attempts into this direction exist, such as the interdisciplinary workshop on the potential of genetics and chemistry for fisheries control and enforcement, held in 2008 at DG Mare in Brussels[46]. Some members of the FishPopTrace consortium participated in this meeting and it was generally felt it was highly informative and productive for both the experts as for the staff of the European Commission.

For capacity building the current infrastructure would certainly have to be improved and to be adapted to an EU-wide approach. A necessary requirement is the establishment of a central database, or a data hub linking to available databases, which is properly curated and adheres to specified quality and validation criteria. For species identification purposes the above mentioned FISH-BOL database can be used. On the other hand for fish population identification and stock management purposes the situation is more complex, though increasingly attainable[47].

To this end the FishPopTrace fully endorses the Commission initiative EMODNET[48], and will undertake required steps in order to support the integration of genetic and chemical data into this endeavour. Moreover we believe that the Data Collection Framework Directive[49], which refers also to biological data, opens up opportunities to better integrate genetic and chemical data into fisheries management under the CFP remit. EU member states should in our opinion be strongly encouraged to take steps into this direction.

In the context of databases and accessibility of valuable data-sets emerging from research projects a severe problem becomes apparent: While there is no doubt that the European Community Framework Programs (FP) provide invaluable support to collaborative research projects on the EU

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[46] Interdisciplinary Workshop on the Potential and Applicability of Advanced technologies based on Biotechnology, Genetics, Chemistry and Forensics for Traceability and Control in the Fisheries Sector. European Commission DG Mare DG JRC, Brussels, 17 June 2008.

[47] Hauser, L. and Carvalho, G.R. (2008) Paradigm shifts in marine fisheries genetics: ugly hypotheses slain by beautiful facts Fish & Fisheries 9: 333-362.

[48] http://ec.europa.eu/maritimeaffairs/emodnet_en.html

[49] Council Regulation(EC) No 199/2008 of 25 February 2008 concerning the establishment of a Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy. Official Journal of the European Union L 60: 1-12 (05.03.2008).

level and beyond, recently the Court of Auditors stressed that under FP6 the large international Networks of Excellence funded to foster innovation and collaboration often fell apart after funding had ended[50]. We observe the same phenomenon for fisheries related research projects, financed under FPs or other schemes. FishPopTrace, in its endeavour to counteract the current dispersal of genetic and other data related to fisheries and aquaculture, has established an inventory of past and ongoing projects following similar and complementary approaches. Furthermore a web crawler tool within FishPopTrace is under development, which allows information to be accessed on data hosted by relevant research databases[51]. However when we embarked on this endeavour it soon became obvious that most projects were supported by databases which had never been publicly accessible and are not managed after the data had been exploited for the specific targets aimed at within the scope of the respective projects. Such focus makes further use of these datasets highly difficult if not impossible, which is a tragic loss of potentially valuable information also for fisheries management. Moreover, if properly implemented and supported by a user-friendly interface, a centralised database would greatly facilitate coherence within the scientific community and catalyse the dialogue among stakeholders thereby facilitating the uptake of genetics, genomics and chemistry into fisheries management. While also the ICES WGAGFM has repeatedly pointed to this problem, and proposed strategies to create an EU wide "fish genetic data hub"[52], it is clear that none of the current stakeholders involved can solve this problem alone.

Conclusions

We delineated how the revolution in DNA technologies along with fast progress in microchemical and isotope analyses, and related areas such as informatics and statistical analysis open up major new opportunities for the CFP to tap into a repository of knowledge and proven applications. Such advancement is already powerfully illustrated by numerous, yet isolated, examples. However to merge modern technologies based on genetics, genomics and chemistry fully into fisheries management under the CFP remit, existing barriers among disparate stakeholders have to be removed. General awareness of what is needed on one side, and what is feasible on the other side, must be created. A formally established permanent and official umbrella body encompassing representation from various stakeholders would promote such dialogue and importantly serve as an interface with end-users and the fishing industry. With the introduction of VMS into the CFP regulatory framework the European Union has already proved its capacity to pioneer the use of advanced technologies for fisheries management. The uptake of molecular and chemical technologies provides another great opportunity to do so. We think, due to its central role in the CFP framework, that the European Commission could play a key role in transferring genetics, genomics and chemistry into a coherent EU fisheries management framework under the CFP remit.

We hope that the current document represents a valuable contribution to the ambitious goal of reforming the CFP, in that it delineates how modern technologies based on genetics, genomics and chemistry can address some of the most notorious obstacles to attaining sustainable fisheries. We remain available for further discussion or clarification.

[50] European Court of Auditors (2009) Special Report No.8 'Networks of Excellence' and 'Integrated Projects' in Community Research Policy: Did they achieve their Objectives?, Luxembourg Publications Office of the European Union, October 2009, ISBN 978-92-9207-408-1.

[51] https://fishpoptrace.jrc.ec.europa.eu

[52] Annual Report of the ICES Working Group on the Application of Genetics in Fisheries and Mariculture (2009).

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