# Recenzja Rozprawy Doktorskiej mgr Dawida Dybowskiego

pt. *Modelowanie wpływu gospodarstw rolnych na przykładzie gminy Puck, na wody morskie zlokalizowane w strefie przybrzeżnej Morza Bałtyckiego (Zatoka Pucka)*

*Modelling the impact of farms, on the example of the Puck Commune, on sea waters located in the coastal zone of the Baltic Sea (Puck Bay)*

## Research aim

The doctoral dissertation of mgr Dawid Dybowski titled „ Modelling the impact of farms, on the example of the Puck Commune, on sea waters located in the coastal zone of the Baltic Sea (Puck Bay)" was carried out at the Marine Ecohydrodynamics Laboratory of the Institute of Oceanology of the Polish Academy of Sciences, Sopot, under the supervision of Prof. dr hab. Lidia Dzierzbicka-Głowacka in the OECD field of Earth and related Environmental Sciences – Oceanography.

The purpose of the research was to determine the impact of nutrient enrichment from farming on confined marine waters in the coastal zone. This overarching objective was achieved through an application of an advance innovative tool, namely a numerical model 3D CESM (i.e. a three-dimensional Community Earth System Model). The PhD candidate developed a new model domain covering the Puck Bay and approaches and utilized an existing 3D CEMBS (3D Coupled Ecosystem Model of the Baltic Sea) model of the Baltic Sea as the source of open ocean boundary conditions. Further goals were set out in order to fulfil the main objective of the research. These are:

- Characterization of the structure and variability of hydrodynamic parameters in the Bay of Puck
- Determination of the nitrogen loading to the Bay and development of an online calculator
- Characterization of the structure and variability of chemical parameters in the Bay
- Analysis of the impact of nutrients supplied to the Bay down the rivers on the waters of the Bay

The approach and methods adopted to attain the above goals and the main objective as well as the main results are subject of a detailed review presented in the following sections.

## Structure of the dissertation

The doctoral dissertation of mgr Dawid Dybowski comprises of three published peer-reviewed journal papers and one submitted paper. The first paper introduces the hydrodynamic model of the Bay of Puck and its validation. The second paper presents the analysis of the scale of nitrogen leaching from the agricultural lands draining into the bay and the development of an online calculator. The third paper describes the biogeochemical model of the Bay of Puck and its validation and the fourth paper, that is currently under a review, analysis the impacts of nutrient loading on water quality in the bay. The journals are all JCR indexed and have quite high IF of c.3 for the field of the subject research.

All publications included in the dissertation have been co-authored by other collaborators with **mgr Dybowski** as the lead and **first author** contributing with **70 to 85%** to the presented work. The co-authors were mostly the scientists working at IOPAN, however, the second paper, concerning the estimates of nitrogen leaching includes also co-authors from the Institute of Technology and Life Sciences in Falenty and from the Municipality of Puck.

The presented research involved the use of all modern tools available nowadays to physical oceanographers, namely, data from in-situ measurements (used for the validation), remotely sensed data (used for both data assimilation and model validation) and a numerical model, an advanced mathematical tool that not only can significantly aid research on ocean dynamics, but can also be used as a predictive tool.

The publications comprising mgr Dybowski's dissertation have already been peer-reviewed by experts in the field. I therefore refrain from providing an additional review of same. My review will comprise of an opinion whether the publications comprise a coherent thesis, whether the subject of the dissertation has been addressed and if the dissertation meets the standards required from doctoral dissertations.

The doctoral dissertation submitted by mgr Dawid Dybowski comprises of:
1) The list of abbreviations,
2) The English and Polish abstracts with the following sub-headings:
   - Introduction
   - Materials and methods
   - Results and discussion
   - Conclusions
3) The list of references,
4) Re-prints of published 3 x peer-reviewed papers and 1 x submitted paper in the form of an attachment,
5) Authorship statements and
6) Acknowledgements.

It should be noted that the Polish Abstract provides more detail than the English Abstract and thus this review focuses on the content of the Polish Abstract and the papers.

## Introduction

The introduction section, along with the Introduction to Research paper #4, adequately set the background to the presented research and discuss why it is important and timely. The process of eutrophication is introduced and its negative effects on the functioning of the ecosystem described. Excessive phytoplankton growth leads to the decrease in water transparency and deoxygenation. Farming practices influence the functioning of coastal ecosystems, as excessive and inappropriate use of fertilizers and associated nitrogen leaching may have serious consequences on coastal marine waters, which, in turn, may impact on the quality of important services that the marine ecosystems deliver and impact on their functioning not only in a short, but also in a long term. Additionally, climatic changes are likely to cause an increased loading of nutrients to the Baltic Sea, and rising water temperatures may further boost eutrophication.

In-situ monitoring of the physico-chemical parameters of marine waters is constrained to localized information and expensive. The adoption of an advanced innovative tool in this research in the form of a numerical model significantly contributes towards a successful attainment of the research objectives. The choice of the study site, the Bay of Puck, is also appropriate, as it is a confined environment, likely to be heavily impacted by anthropogenic activities, such as farming and associated fertilization, and likely to be sensitive to any changes resulting from the implementation of various management measures as well as to the climatic changes.

One criticism I have is the lack of the review of previous research on the functioning of the Bay of Puck ecosystem. Outside of one reference to the paper by Węsławski et al. (2013) in paper #3 and one reference

to the paper by Miętus et al. (2009) in paper #4, I struggled to find even a brief paragraph on what is currently understood about the ecological process in the study area, which would convince the reader that it is important to study it and advance our knowledge. Some monitoring data is presented in papers 3 and 4, however, the analysis of this data is confined to the context of the model validation (paper #3) and to the presentation of the statistics (e.g. means and annual minima/maxima) in paper #4. A literature review specifically concerning the ecological processes, at least at the lower trophic levels, in the Bay, would augment the dissertation.

## Materials and methods

This section presents details of the setup of the EcoPuckBay model, which is based on well-established Community Earth System Model (CESM). The CESM model has been previously used at IOPAN as the numerical engine behind the operational model of the Baltic Sea, 3D CEMBS, running at 2.3 km horizontal resolution. The 3D CEMBS model provides boundary conditions to the EcoPuckBay model, which itself runs at 115 m resolution and with a total of 24 vertical layers using the z-level discretizartion. However, a discrepancy in the specified number of vertical layers is noted in the dissertation, as the attached paper #4 reports 33 vertical layers used. This raises the question if the configuration of the model used in the research presented in paper #4 is still the same as in paper #1 or has the model been modified since? If the latter is the case then a note of caution needs to be issued, as such change will affect the model skill and the validation results of the physical part presented in paper #1 are likely to be different to a certain degree, which is impossible to determine until such validation is carried out.

Main assumptions and equations of CESM physical model are presented with only a high level information on its biogeochemical (NPZD) module. As regards the latter, the reader is referred to the paper by Dzierzbicka-Glowacka et al., 2013, instead, for more detail. Details of the atmospheric forcing applied (the meteorological forecasts from the Interdisciplinary Centre for Mathematical and Computational Modelling of Warsaw University) and river forcing (HYPE model) are also provided. Additionally, in the research on the biogeochemical cycling in the Puck Lagoon, results from two further models working in operational mode were included in EPB by mgr Dybowski, namely groundwater flow model, MODFLOW, and a surface runoff model, SWAT.

The validation of the EcoPuckBay, both its physical part and biogeochemical part, is included and points to a good level of the model skill and mgr Dybowski is to be congratulated on this achievement. One observation I would like to make, though, is the fact that the model was not only validated against data from monitoring (e.g. from VIEP), but also compared to the outputs from the Baltic Sea's Copernicus model, NEMO-Nordic and NEMO-SCOBI, showing an improvement compared to both. However, an obvious question that springs to mind is why was the model not compared to its parent model, 3D CEMBS? This would significantly strengthen the outcomes from the research, as it would clearly answer the fundamental question – was it worth investing in a high resolution model for the Bay of Puck given that a larger scale model already exists? Do we see a significant improvement in the skill? The answer is most likely yes, as the 2.3 km model is too coarse to resolve the Bay of Puck, but so is the Copernicus' 4 km model.

On a final note, as already mentioned, it is reiterated here that section 2.2.2 (and 3.2.2) should contain, for the benefit of the entire dissertation, a literature review of the ecosystem functioning in the Bay of Puck, which would set a background and motivation for the presented research.

## Results and discussion

Presentation and discussion of the results follows a logical structure and commences with the report from the validation of both the hydrodynamic (paper #1) and biogeochemical model (paper #3).

An extensive validation of the hydrodynamic model has been carried out against the monitoring data from VIEP, s/y Oceania and also through a comparison with NEMO-Nordic model. Standard statistics frequently used by ocean modellers were computed and they show good model skill and thus confirm its suitability as a trustworthy tool that can be used in further research. Similarly, the biogeochemical model was validated against data from VIEP and also against NEMO-SCOBI. The obtained statistics may not look as impressive at the first glance, however, it is very difficult to create a robust biogeochemical model and the obtained statistics, with e.g. the values of r of the order of 0.6-0.7, are in fact quite typical for biogeochemical models. One shortcoming and a missed opportunity is the lack of a comparison of the EcoPuckBay model to its parent model, as already mentioned in this review.

An interesting, albeit somewhat disconnected part of the dissertation is the section and the paper on the estimation of nitrogen leaching from the farmlands and the development of an online calculator. It is nice to see such tool being widely available online so that an awareness can be raised amongst the farmers themselves, whereas the agricultural management authorities can utilize this tool in the advisory and management processes and work with individual farmers in order to reduce leaching. I struggle, however, to find a connection between this part of the dissertation and the main subject, which is the research on the impact of farming on sea waters in the Bay of Puck through modelling. Neither paper #3 nor paper #4 make reference to paper #2 and the results presented in paper #2 did not seem to be used and followed up by mgr Dybowski in his subsequent research. In particular, the reader does not know how much of nitrogen that presently enters the Puck Lagoon through the four rivers is the nitrogen leached from the farmlands and what would it be if the remaining 50% of the farms achieved the ideal 0 kg N leaching, i.e. no leaching in the Puck Commune. Furthermore, what impact it would have on the ecosystem functioning in the Puck Lagoon and Bay? Instead, the reader is presented with an unrealistic scenario, whereby nutrient supply through the four rivers draining into the Puck Lagoon is shut down completely – a scenario that will never materialize. Furthermore, it would also be good to see some validation of the outputs obtained in this research so that the reader is informed about the accuracy of the calculator. If it is impossible to verify the calculator at present due to a lack of appropriate monitoring, a short statement could have been included. It is good to see some comparison with the leaching estimates in Sweden from the farmlands of a similar characteristics to those in the Puck Commune. As reported, the leaching estimates obtained by mgr Dybowski are below the recent values reported in the south-west of Sweden and at a lower range of estimates for the south of Sweden in an older research (end of the 20$^{th}$ century). It is a very interesting outcome given the fact that an average N fertilization rates in the Puck Commune is approximately 3.5 times greater than the average N fertilization rates in Sweden.

I find research presented in paper #4 most interesting. It uses the numerical model EcoPuckBay, coupled with SWAT catchment model to study the impacts of nutrients enrichment from the land on the ecosystem functioning in the Puck Lagoon. As already pointed, it is disappointing not to see the utilization of the results presented in paper #2. Instead, an extreme case of the total shutdown of the nutrient supply down the four rivers was studied, which is interesting in its own way, though. The main outcome is that the four small rivers that drain into the Puck Lagoon can indeed significantly alter the blooms of phytoplankton in the Lagoon. I am a bit confused as regards the reported results. There are some discrepancies between the statements and the Figures presented in the dissertation. Upon careful reading, it emerged that the colours on Figures 6 and 7 are flipped. The overall finding is that the shutdown of the nutrient supply, whilst limiting the growth of diatoms in the spring, causes an increase in the diazotrophs (cyanobacteria) in the summer. This is due to the fact that less N results in less diatoms in the spring, and the excess P left stimulates more growth of cyanobacteria in the summer. This is a very interesting outcome, as it is counterintuitive – a drastic reduction

in nutrient supply caused an increase of the harmful algae biomass. It confirms the complexity of the coastal ecosystems that the scientists and managers must be continuously aware of in their research and management decisions. Advanced tools, such as the presented numerical model, are useful aids in the process of gaining knowledge and transferring this knowledge to the management authorities, as demonstrated in this dissertation. One concern I have to raise though is the limited time period of 6 months over which the model was run. Depending on the residence time of water in the Puck Lagoon, on which there are not any comments in the dissertation, this potentially could have been too short time period for the new steady state to develop and the impacts in subsequent years could be different from what was modelled over the first 6 months. We could see further reduction of nutrient concentrations in the Lagoon. An interesting extension to the presented research would be the analysis as to how much nutrients enter the Lagoon from the Bay of Gdansk, i.e. the local input vs the input from an open sea. This would give a context as to what degree the local ecosystem is influenced by the local nutrient inputs and to what degree by far-field inputs.

## Concluding remarks

Mgr Dawid Dybowski submitted a solid doctoral dissertation that presents a newly developed advanced mathematical tool to study physico-chemical processes in the coastal environment of the Bay of Puck and Puck Lagoon. Furthermore, a historical model data and 48 hour forecasts are available online through an interactive portal www.waterpuck.pl, as is a calculator of N leaching from the agricultural lands in the Puck Commune, which can support and test management decisions aiming at reducing leaching.

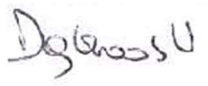
Mgr Dybowski demonstrated that the skill of the model in representing both physical and biogeochemical processes in the Bay of Puck is good and thus the tool is ready to be used in the investigations into the spatio-temporal characteristics of biogeochemical cycling in the Bay and for testing the 'what-if' scenarios, such as the presented shut-down of the nutrient supply from the rivers within the Puck Commune.

I am satisfied that the four aims set out above have been achieved by mgr Dybowski, however, I was expecting to see more content directly reflecting the title of the dissertation, i.e. the impact of farms. Whilst the scenario in which the local nutrient supply from the land sources within the Puck Commune is interesting and sets a perspective as to its impact on the ecosystem functioning, i.e. what would happen in an extreme case of the lack of local sources, mgr Dybowski did not elaborate in detail as to what realistically is possible in terms of the nutrient input reduction from the farmlands within the Commune, as suggested by the actual title of the dissertation. Such scenario, could, for example, be zero N leaching from all farmlands, but nutrients from all other sources still being present. An extreme case revealed quite a significant impact, but what would a more realistic scenario show? The question as regards the amount of nutrients imported into the Lagoon from the sea is also open, and in case it is significant compared to the local inputs from land, it would point to the need of a more integrated nutrient input management across the Gulf of Gdansk when considering the management plans for water quality in the Puck Lagoon. In particular, as presented in Table 2 in paper #3, Vistula river is by far the most significant source of nutrients in the region. This raises concerns that local efforts may be meaningless without concurrent reductions throughout other sources.

Notwithstanding the above comments, I congratulate mgr Dybowski on the presentation of a solid dissertation, and being an ocean modeller myself, I appreciate the amount of work that was committed to set up the physical and the biogeochemical 3D CESM models and the online calculator, resulting in less time available for carrying out a more in-depth research addressing the above questions. It is also of paramount importance that the developed tools are of high quality in terms of their accuracy, as only then they can serve the purpose. Mgr Dybowski demonstrated that these tools are fit-for-purpose and thus I am expecting they will support further research around the topics addressed in the presented dissertation and beyond in many years to come.

The dissertation fulfills the conditions for doctoral dissertations set out in the Act on Academic Degrees and Titles. Therefore, I am requesting that **mgr Dawid Dybowski**'s dissertation be admitted to the public defence.

Yours Sincerely,



dr inż. Tomasz Dąbrowski