SUSTAINABLE SEAS | Ko ngā moana whakauka | National Science Challenges

Innovation Fund Research Proposal Template

A. PROJECT TITLE

A feasibility study of coastal acidification mitigation strategies for the mussel industry

B. PROJECT TEAM

Project Leader:	Investigators:
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C. ABSTRACT

Acidification of coastal waters is a potential threat to the sustainability of New Zealand's shellfish aquaculture industry. This proposal will provide the first proof-of-concept test of the potential of two remediation techniques - return of waste shell and aeration – to mitigate the impacts of low pH in mussel farms. Laboratory experiments will test and optimise the efficacy of shell dissolution and aeration, and the impact of these techniques on water chemistry will be modelled at farm and local scales in two regions, the Top-of-the-South Island and the Firth of Thames. The effect of the projected change in pH achieved by these methods on the survival and condition of mussel spat and juveniles will then be assessed. Results will be published in the primary literature, with a synthesis report to the shellfish industry containing recommendations for subsequent field deployment. If successful, these techniques may have benefits beyond shellfish aquaculture, in mitigating coastal acidification in coastal ecosystems.

D. RELEVANCE TO CHALLENGE OBJECTIVE

This research addresses the primary objective of the *Sustainable Seas* Challenge of optimising utilisation of marine resources within environmental constraints. By assessing remediation strategies to combat coastal ecosystem deterioration and potential decreased productivity of the shellfish industry, it aligns with 2.2.2. in generating environmental and economic benefit in the coastal zone and adding value to the marine economy. This research provides a climate change component to the Challenge, a link to national ocean acidification research, and represents a unique opportunity to proof-test a practical strategy for mitigating climate change impacts, that will benefit the New Zealand coastal economy.

E. INTRODUCTION

Acidification of coastal waters results from the uptake of anthropogenic CO_2 from the atmosphere, compounded by respiratory CO_2 production during bacterial degradation of organic matter. This represents a significant threat to coastal ecosystems, particularly to the viability of molluscs as declining carbonate availability will influence spat survival and development, and growth and condition of juvenile and adults[1]. In addition to the potential loss of ecosystem functions that molluscs provide[2], this may significantly affect shellfish aquaculture sustainability. Impacts on molluscs are recognised as a global issue[3], with recent losses of ~80% in oyster hatchery production in the N.W. USA attributed to ocean acidification[4]. Low pH affects mussel physiology, with reports of increased mortality, thinner shells and weaker byssal attachment[5-8]. Greenshell mussels (GSM, *Perna canaliculus)* may be particularly sensitive as their shell is primarily aragonite, the more soluble form of carbonate, making shell maintenance more challenging under low pH[1]. The GSM industry (2011 revenue $220M; *NZ Aquaculture*) has recently experienced major spat failures and slower growth rates with socio-economic repercussions[9], that may be exacerbated by acidification. The Firth of Thames, which supports ~20% of NZ's GSM industry, experiences seasonally low pH (see Fig.1.), equivalent to values projected for the open ocean in 2050.

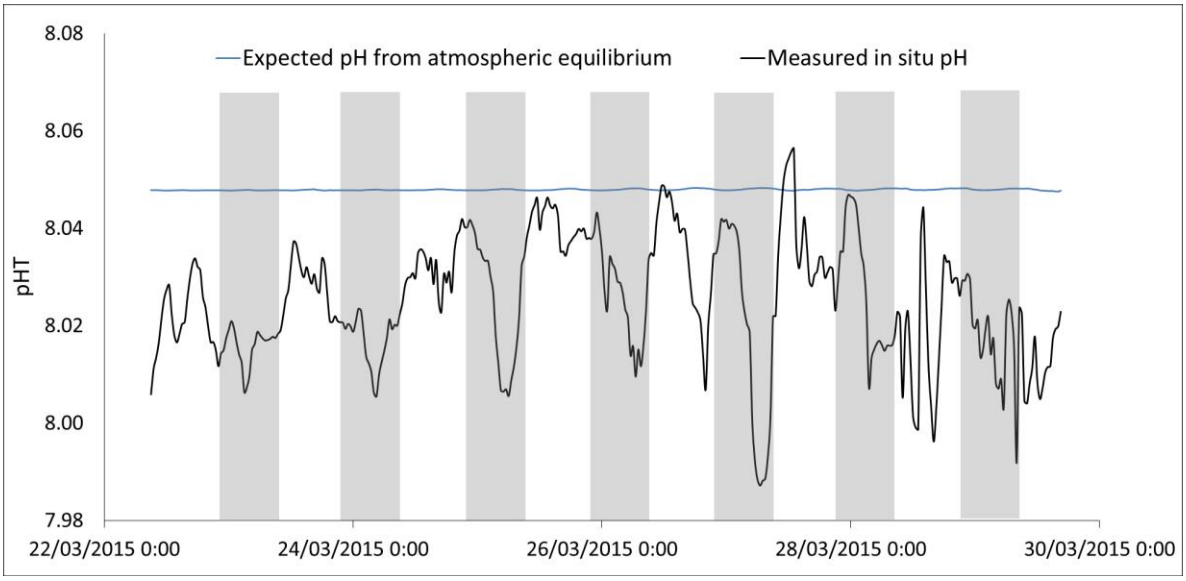

Figure 1. pH at 5m depth in the inner Firth of Thames in late summer (22-30/3/2015, black line). Expected pH is calculated from equilibrium with ambient air (400ppmv CO_2, blue line) with the diel pH minima (21:00-09:00) shown in grey boxes (K. Currie, NIWA).

Adaptation measures to address oyster spat decline in the US have proven successful[10], and there are potential low-tech options for deployment at mussel farm scales. Mollusc shells are a temporary sink for alkalinity in coastal waters and following mortality their dissolution rebalances the carbonate system[11]. Yet, GSM shells are considered as waste by the industry and discarded on land, with resulting loss of natural buffering capacity. Removal of >20,000 tonnes of GSM in the Nelson/Marlborough region (1960-1984) represents a significant carbonate loss[12]. Tests on shell return to sediment show positive responses in bivalve survival and recruitment[13], and there may be parallel benefits of using waste GSM shell to buffer coastal acidification around mussel farms. Coastal waters experience pH minima at night, from respiration in the absence of photosynthesis, and also episodic pH minima associated with storms and high run-off. There is further potential to remove this excess CO_2 by strategic aeration of water to alleviate pH stress around mussel farms during these periods. This proposal details a proof-of-concept pilot study to determine the efficacy of these potential remediation strategies prior to deployment. These low-tech strategies for enhancing resilience, increasing productivity and reducing wastage in mussel farms will be assessed for the Firth of Thames and the Top-of-the-South regions. This research will optimise marine resources utilisation within environmental and climate constraints, with potential additional benefits in managed coastal systems such as mātaitai and taiāpure, and natural reef ecosystems.

F. AIMS

- Evaluate two innovative in situ remediation approaches - a) returning shell material to raise carbonate saturation and pH, and b) strategic aeration to ameliorate low pH resulting from organic matter respiration and extreme meteorological events - to assess their efficiency at reducing the impacts of coastal acidification on New Zealand mussel farms
- Apply a multi-disciplinary best team approach and cutting-edge experimental systems to assess the potential merits of these remediation applications. The research programme will (a) determine the potential efficacy of both approaches in laboratory-based studies to (b) inform hydrodynamic model estimates of their impact at farm and local scales, and c) carry out manipulation studies to assess their impact on the settlement, growth and condition of GSM spat and juveniles.
- Produce a primary literature publication, and a synthesis report for the shellfish aquaculture industry and stakeholders with recommendations for subsequent field trials and implementation.
- Provide advice on these low-cost low-tech approaches for improving yield success and economic performance of the New Zealand GSM industry, and potential ecological and socio-economic benefits in other managed coastal waters.

G. PROPOSED RESEARCH

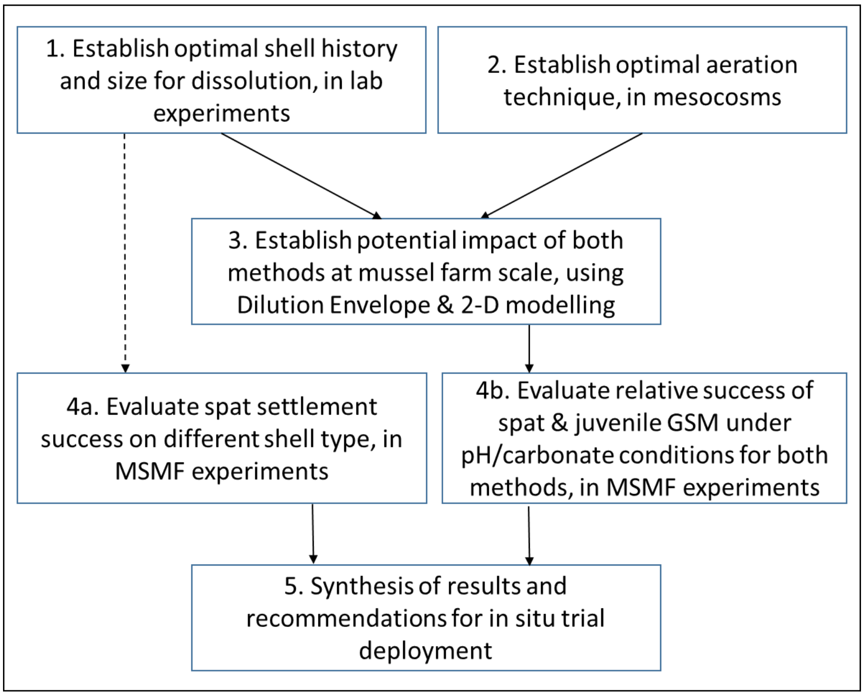

Fig. 2. Work programme detailing the steps to establish the efficacy of both approaches prior to in situ field testing. This benefits from our research skills and experience in measurement of pH and the carbonate system, gas exchange, coastal hydrodynamics, and shellfish physiological response to stressors; and also from access to ancillary field data including the New Zealand Ocean Acidification Observing Network (NZOA-ON), collaboration with the CARIM (Coastal Acidification: Rate, Impacts and Management) project, and stakeholder co-funding and support.

1. Carbonate dissolution experiments

Prior to deployment of shell return techniques it is essential to establish the dissolution rate of shell material, and the factors that influence this. This will be assessed in laboratory experiments using GSM shell incubated in ambient coastal seawater in an automatically-controlled pH-stat method[14]. Seawater pH will be adjusted by acid addition to determine the relationship between Ω (the carbonate saturation state) and the shell dissolution rate, and this relationship then used to calculate dissolution rates at different pH values, and so the potential buffering capacity. The experiments operate within a target pH ± 0.01 units, with an acid aliquot added when the solution pH exceeds the upper pH tolerance limit. Total alkalinity will be determined by potentiometric titration with hydrochloric acid, with the system calibrated by Tris/HCl buffer and a Radiometer Analytical Silver/Silver chloride electrode. All parameters will be calculated using the SWCO2 programme[15], which interfaces with the automated pH-stat programme. These measurements will provide dissolution rate and mass loss of incubated shell material, in a series of experiments to assess the influence of the following factors:

a) shell history, by determining relative dissolution of i) fresh GSM shells; ii) aged GSM shells (eg. dried and held in land-based waste piles for >6 months) and iii) fresh and aged GSM shells exposed to coastal sediment for a period of 3 months. Research on oyster shells indicates that fresh and aged shells have a higher dissolution rate than dredged shells, with rates ranging between 2 to 70% per annum[16].
b) shell size, by determining relative dissolution of i) whole GSM shell, ii) coarse GSM shell fragments and iii) crushed GSM shell. Research on bivalve shells confirms that size is a critical factor influencing carbonate dissolution[17], and that crushed shell is effective at enhancing infaunal bivalve recruitment[18]. As crushed shell will have a higher surface area we assume that dissolution rate will be highest; however we will also test shell fragments as this form is more amenable to suspending in the water column.
c) Shell condition - An increase in shell surface area due to boring organisms may accelerate dissolution, whereas epiphytic settlement and organic coating of shell material may reduce dissolution[16], and so the relative dissolution rate of eroded shells, and those with biofilm, will be assessed. In addition processing of waste shell using heat will be assessed to determine its influence on dissolution.

The results of these laboratory tests will determine the optimum shell mode, size and condition for dissolution, and will be critical in establishing the potential of waste GSM shell for offsetting coastal acidification.

2. Aeration technique

Aeration has been recently recognised as a potential strategy for elevating pH[19]. Coastal pH may vary by 0.1 on a daily basis, with nocturnal pH declining to <8.0 in late summer in the Firth of Thames relative to the expected pH of 8.05 from equilibrium with atmospheric CO_2 (see Fig. 1). Strategically-timed aeration at night may partially counteract this by sparging excess CO_2 from the water into the atmosphere. In addition to reducing pH stress, this increased ventilation may have additional benefits of elevating dissolved oxygen at the period when hypoxia is most significant, and also reducing near-surface stratification which promotes CO_2 accumulation and hypoxia in subsurface waters. Reducing coastal acidification and hypoxia concurrently may then have a "double-whammy" effect by reducing their individual and interactive effects[20].

The diel pH trends and pH minima in both regions will be established using monitoring data collected by in situ SeaFets pH sensors as part of CARIM. This will be followed by evaluation of factors limiting and enhancing efficacy of the aeration technique:

a) Evaluation of aeration options – Degassing systems, such as CO_2 strippers and aeration towers, are used in aquaculture hatcheries[21], but will be less effective and costly to deploy in coastal waters. However, bubble curtains, which are used for large-scale applications, such as oil spills containment and sediment control in aquatic systems[22], may be more viable. We will assess different aeration approaches for CO_2 removal and pH control, including bubblers, micro-diffusers and permeation tubing, to identify the optimal type for further tests.

b) Establish optimal timing and flow of aeration in relation to in situ diel pH variability.

c) Determine the influence of aeration depth and relative positioning in the mussel farm.

These evaluations will be in part be carried out using the new mesocosm facility at NIWA Wellington, which has the capability to control pH and temperature in nine 4000-litre bags of coastal seawater.

3. Dilution Envelope and hydrodynamic modelling

Lateral advection and dispersion around a mussel farm will potentially reduce the effectiveness of both remediation strategies. At this proof-of-concept stage the focus is on a farm-scale dilution envelope model based on coarse data and diffusion characteristics[23] in the same way as quantified with a tool like DEPOMOD[24]. This will be informed by regional data relating to flow and embayment characteristics and reflects different hydrodynamic situations. Sensitivity to local structure-induced diffusion can then be quantified and compared with data around farm arrangement dilution[25]. Challenges in this work component relate to flow-structure interaction and water mass retention in the vicinity of the reacting material, which are not normally considered mechanistically in tools quantifying flows around aquaculture facilities. While beyond the scope of this proposal, if 1 and 2 above prove viable, this modelling would identify a pathway for development of enhanced tools at this scale. The key steps in this component are (i) identification of "background" flow and variability metrics, (ii) determination of farm-induced dilution, (iii) ingestion of geochemistry fluxes, and (iv) development of design diagrams to inform potential impact.

An important consideration for the effectiveness of these techniques is their area of influence, and whether transport and diffusion minimise effects at the farm scale. We will use simplified modelling approaches to estimate the area of influence that the proposed interventions might have. Following Plew (2011)[26] , 2D depth-averaged hydrodynamic models, that include the influence of the drag from the mussel farms, will be used to estimate the area of influence by using tracers subjected to advection, diffusion and decay processes. This will include the hydrodynamic effects of the farm structures, which is essential for assessing nearfield effects. While the 2-D approach lacks complexity associated with vertical structure in stratification and velocity shear, it will provide a meaningful test of whether the remediation techniques are effective in both the near-field and bay-scale. This will allow comparison between low-current/low dispersal sites and high-current/high dispersal sites, so providing guidance on where the techniques may be most effective. Another proposal to the Challenge Innovation Fund (*River plume forecasting by integrated catchment/oceanic modelling*) will conduct high-resolution 3D hind-cast modelling of Pelorus Sound and Tasman/Golden Bay and, if funded, will provide more rigorous assessment of dispersion in and around the sites which may be applied to this proposals findings.

4. Influence of remedial approaches on GSM growth & condition

In assessing the remediation strategies it is important to establish not just their efficacy in elevating pH and carbonate saturation state, but also that they have a positive effect on mussel survival, condition and growth. We will use GSM spat, and juveniles of the size and age routinely out-planted to mussel farms, to evaluate their response to the adjusted pH trends for the remediation techniques, as projected by the experimental and modelling results in 1-3 above. For the *shell return* pH trend, pH will be elevated relative to ambient pH for the entire 24 h cycle, whereas in the *aeration* technique assessment, pH will only be elevated at night. GSM will be sourced from the Top of the South Island, with transfer to the experimental facilities at NIWA Wellington (Marine Environmental Manipulation Facility (MEMF)). Experimental temperature will be based on ambient conditions at the collection site, and incubations will last several weeks. We will assess timing and characteristics of larval development and, for juveniles, we will evaluate overall growth, physiological and physical condition, respiration rates, and shell strength and integrity, using established methods[27-29]. Survival rates of both life stages during the experiments will also be quantified.

Restoration of shellfish reefs through addition of waste shell is a strategy that is being explored in NZ[12,30]. Studies have shown that dissolution of oyster shell material decreases with age[16], and so reef building might require aged shell for longer-term success. If the results of the carbonate dissolution experiments investigating shell history (see 1a, above) indicate significant differences, we will carry out additional experiments to assess the suitability of both fresh and aged waste shell for successful GSM spat settlement. Together with the results on influence of shell history on carbonate system buffering, this will provide valuable information on the utility of artificial shell reefs to enhance natural GSM recruitment.

5. Synthesis

Results will be presented at the New Zealand Ocean Acidification workshop in 2018, and synthesised in a primary literature publication and also a feasibility report for the shellfish aquaculture industry and stakeholders. The results of 1-3 will inform assessment of the economic viability of both approaches; for example, shell return will involve additional transport, deposition, and potentially shell processing costs, and an air delivery system of sufficient air volume delivery will be required for aeration. The latter would need a suitable power supply, which could be delivered using renewable energy technologies (solar, wind or tidal pumping) on the mussel farm. Once the scale of the aeration technique (e.g., pumping volume and hardware) is established the economic viability can be assessed. The feasibility report will compile the findings on efficacy and economics with practical and logistical considerations to inform subsequent field studies and deployment of these techniques.

H. RESEARCH ROLES

Researcher	Organisation	Contribution
C. Law	NIWA/University of Otago	Project Leader, Lead scientist on Outputs 2 & 5, marine biogeochemistry
K. Hunter	University of Otago	Lead scientist on Output 1, marine carbonate chemistry
V. Cummings	NIWA	Lead scientist on Output 4, shellfish ecology and physiology
C. Stevens	NIWA/University of Auckland	Lead scientist on Output 3, footprint modelling, Lead on 4.22
D. Plew	NIWA	Hydrodynamic modeller on Output 3
J. Murdoch	University of Otago	Technician on Output 1, marine carbonate chemistry
N. Barr	NIWA	Technician/Engineer on Outputs 2 & 4
S. Allen	NIWA	Technician on Output 4

I. LINKAGES AND DEPENDENCIES

This proposal builds upon and complements different components of the MBIE CARIM (Coastal Acidification: Rates, Impact and Management) project. Although CARIM will develop models and tools for management of coastal acidification, this project will address the next step of OA mitigation adaptation by testing in situ remediation approaches. Data on pH variability and frequency of low pH events at both study locations will be provided by CARIM and the NZOA-ON. Information generated by CARIM on GSM life history sensitivity will inform the experiments testing the impact of the remediation strategies on GSM growth and condition, and tests on spat will share experimental approaches with CARIM.

If the geochemistry aspects of this research prove viable, and the Dilution Envelope model approach indicates the impact is sufficiently contained volumetrically, this work will connect with Sustainable Seas 4.2.2. This work-package will develop knowledge at the near-field scale, and identify ways in which it can be ingested into ecosystem management tools. This proposed research also has synergies with NIWA Core-funded research on dilution of aquaculture impacts which, although currently focused on fin-fish aquaculture, has previously developed dilution simulations around shellfish structures[32-33].

The research will also complement proposed projects under development to use shell return for restoration of natural mussel beds[30]. Although amelioration of low pH is not a component of these restoration studies it provides an opportunity to extend the measurements and apply the techniques and results of this proposal. This project will also benefit from ancillary data from carbonate system monitoring in the Firth of Thames currently within NIWA Core-funded research, and from experimental approaches and facilities developed by NIWA Core research, including the manipulation and mesocosm facilities. The research will also have access to new laboratory facilities in the Department of Chemistry at the University of Otago.

J. RISK AND MITIGATION

There are few impediments to the proposed assessment of the two remediation approaches, as measurement and experimental facilities and models are functional and available, and external data sources confirmed. There are potential impediments to the implementation of the remediation techniques if this pilot study confirms their effectiveness. At present there is a ban on returning shells in some regions, although the consent process is being actively addressed (S. Urlich, Tasman District Council, pers. comm.) and will benefit from knowledge delivered by this research. Return of shell material to the seabed below mussel farms may alter the benthic community, although studies to date indicate positive benefits from restoration of natural shellfish beds[12,30]. Biosecurity risks via introduction of other organisms with returned shells are minimal. Shell return may alter surface benthic habitat and provide niches for undesirable and invasive species; however research indicates that it may stimulate natural mussel bed, providing positive impacts on ecosystem services and function that benefit biodiversity, water clarity and fish biomass[12,30,33]. The costs of deploying shell addition and aeration at suitable scales may prove prohibitive, but this will be determined in this study following confirmation of the efficacy of both approaches.

K. CO-FUNDING AND INDUSTRY SUPPORT

The proposed research has a total co-funding of $50K. Waikato Research Council (WRC) is developing a new Regional Coastal plan which requires information on coastal acidification mitigation and shell return to develop new policy around consents (H. Giles, WRC, pers. comm.); consequently WRC have offered co-funding of $20K p.a. to support the Firth of Thames research. Tasman District Council (TDC; S. Urlich) have offered $10K co-funding to support the shell return research, to inform a restoration initiative they are preparing for Marlborough Forests Growing Levy trust (*Ameliorating the effects of forestry on coastal water quality through mussel reef restoration*). Alignment with CARIM and NZOA-ON will provide infrastructure support, with supporting data also made available by NIWA from the Firth of Thames and Tasman Bay Moorings (supported by TDC at $4.5K co-funding).

The NZ mussel industry is cognisant of the threat of acidification, and the proposed research has the support of the mussel farm owners and advisors, including Rob Pooley (Just Mussels Ltd, Nelson), Jake Bartrom (Bartrom Whanau Mussel Farm, Waimango, Firth of Thames), John Wilson (Wilsons Bay Area A, Firth of Thames) and Robin Britton (Focus Resource Management Group, Wilsons Bay Area B). They have provided useful information on potential issues around shell return, including the consent process and benthic change surveys that are required on mussel farms, and also identified waste shell sources at Havelock (South Island) and at OP Columbia in Whitianga that could be used. The *Revive our Gulf Mussel Reef Restoration Trust* (Rebecca Bartley) are also interested in collaboration and, although reef restoration is not the primary aim of this proposed research, there will be co-benefits from the assessment of shell return for the Trust.

L. VISION MĀTAURANGA (VM)

Māori attach significant cultural value to coastal resources within their rohe, and GSM are an important source of kaimoana and so protein. Many iwi are engaged in the shellfish aquaculture industry, and so the potential economic benefits from the increased productivity and value delivered by these remediation strategies may accrue to Māori. Furthermore iwi may derive broader benefit from application of these strategies to other managed coastal ecosystems, such as mātaitai and taiāpure, and also coastal reef locations where shellfish are gathered. Ngati Paoa in the Firth of Thames region are well-informed on the issue of coastal acidification, following a hui on the CARIM project at Wharekawa marae, Kaiuau. Lucy Tukoa (Ngati Paoa) has identified a number of benefits of shell return, and advised on the potential issues of transfer of take between rohe, biosecurity, and tikanga, and recommended further discussions with the Pare Hauraki Fisheries Trust, which looks after the interests of Hauraki Gulf Iwi. We have also consulted with the *Tai Timu Tai Pari Stakeholder Working Group* (Richelle Kahui-McConnell), who are supportive of the research.

M. CONSENTS AND APPROVAL

When transferring GSM from the Top of the South to NIWA Wellington for experiments, we will ensure that all MPI biosecurity requirements are met. Our MEMF is PC level 2 accredited, and all water from the facility is treated prior to discharge. Although there is no fieldwork component or deployment in this project, we will inform the appropriate Runanga and Iwi of the results of this project.

N. DATA MANAGEMENT

Data from the laboratory and experimental facility tests will be held at NIWA, with the results and interpretation distributed to the shellfish aquaculture industry and other stakeholders in a report, and also in a scientific publication.

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