STUDIES ON COASTAL AND DESERT DUNES, AND COASTAL SYSTEMS

by

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Declaration page

I declare that the material contained in this thesis has not been submitted by me to any other University for the award of any degree.

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Acknowledgement

The path that I have taken, and the research I have carried out since 1974 when I began my Masters, would not have been possible without the emotional, physical and financial support of many people. Firstly and foremost, I owe a debt of gratitude to my mother, Moira Jean Hesp (nee Fanning, born 1/1/1927) who always provided love and support when I needed it and never questioned my chosen career. To Dr. Graziela Miot da Silva Hesp, my wife, without whose support, encouragement and love I would not be writing these words. To my father also, who taught my siblings and I the immense value of music and song, and who, despite the hard times, bought me my first guitar.

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Dedication

This work is dedicated to my wonderful children, Jonathan Rory Hesp (b. 1976), Phoebe Kathleen Hesp (b. 1980), Sebastian James Hesp (b. 1984), and Nicolas Sian Silva Hesp (b. 2009). Forgive your father his transgressions and for dragging you to the beach and dunes multiple times against your wills, and be the absolute best you can be.

Abstract

The research achievements of the author, relating to the study of coastal dunes, desert dunes and coastal ecosystems in various coasts and deserts of the world are described. These studies began during a period when the morphodynamics approach was in its infancy, and when the "Australian school" of coastal research was just beginning. In this thesis, the research achievements of the author, and the publications, are detailed in the Preface. The thesis comprises 80 selected publications in refereed journals and books. The author's curriculum vitae follows in Appendix 1, and a brief career history is provided in Appendix 2. These selected publications extend over a period from 1981 to May, 2013, during a time when the author held 11 positions and visiting fellowships in several countries. Significant achievements include (i) the first wind tunnel and field study of flow around an isolated plant and the formation of shadow dunes, (ii) studies on the initiation and evolution of incipient foredune types, (iii) a ecogeomorphological classification of foredunes and analyses of their internal sedimentary structures, (iv) contributions to the understanding and classification of beach ridges, (v) studies of the flow dynamics in bowl and trough blowouts, (vi) studies on transgressive dunefield and dune sheet initiation, geomorphology and evolution, (vii) surfzone-beach-dune interactions and model; (viii) flow dynamics over foredunes, (xi) furthering our understanding of barchan morphometrics and flow, and (x) climbing dunes forming via the operation of reversing offshore winds. Discoveries include the following: (i) the relation between shadow dune morphometrics and plant morphology; (iii) surfzone-beach-dune interactions and a model of these interactions and dunefield evolution; (iii) jet flows and dynamics in trough blowouts, including the nature of topographic flow steering in such blowouts; (iv) the morphometric relationships between trough blowout erosional morphologies and depositional lobe morphologies; (v) linear dunes can migrate laterally, (vi) the relationships between faunal abundance and species richness and nebkha size and plant species type; (vii) the nature of speed-down and speed-up within vegetation up a foredune stoss slope; (vii) jet flow over foredunes; (viii) trailing ridges may be produced from the margins of transverse dunes, (ix) the dunes on Saturn's moon, Titan, may be linear (rather than transverse) due to the 'sticky' nature of the sediments, and (x) the existence and species of phytoplankton in South Australian surfzones.

PREFACE: SUMMARY OF RESEARCH THEMES IN COASTAL AND DESERT DUNE AND COASTAL SYSTEMS

INTRODUCTION

An application for assessment for examination for the Doctorate of Science degree (Massey University consists of a collection of papers and articles published in international peer-reviewed journals and books. The research work presented herein was conducted during the past 32 years over the period 1981 to early 2013.

Included in this application are two papers (Hesp, 1981; Short and Hesp, 1982) which were submitted to journals while I was writing my Ph.D., but which appeared after I had finished my Ph.D. thesis research. They are included here to provide the reader with an opportunity to gauge the initial origins of the next 30 years of research and the directions that research took.

An initial research focus on geomorphology, and then Quaternary and coastal geomorphology began in New Zealand in the early 1970's in the Department of Geography at Massey University under the tutelage of Dr. John McArthur who introduced me to the wonders of physical geography and geomorphology, and Dr. Mike Shepherd who supervised my MA (Hons) thesis research on the evolution of the lower Manawatu floodplain (Hesp and Shepherd, 1978). Both gentlemen were marvelous teachers. In 1976, those beginnings were honed further, when under the initial impetus provided by Dr. Bruce Thom (then in the Department of Geography, University of Sydney), I became interested in coastal dune geomorphology, dynamics and evolution. Over time, a holistic interest in all things coastal and aeolian also developed and while my primary focus on coastal dunes remained, other research foci in both the coastal and desert arenas were also developed and expanded.

The following details the paths and themes taken to date, and includes selected papers and articles pertinent to those themes. Articles included in this D.Sc. follow this preface. A complete list of all publications to May 2013 is included in Appendix 1. Appendix 2 provides a brief career history to date, and is included to assist in explaining the somewhat diverse nature of the research I have undertaken.

THEME I: FOREDUNES

Foredunes may be divided into two types, incipient foredunes and established foredunes.

Incipient Foredunes – Initiation, Formation, Dynamics and Evolution

At the beginning of my Ph.D. in mid-1976, the literature on incipient foredunes (or newly developing foredunes; also termed embryo dunes) and established foredunes (older, more developed foredunes) comprised a multitude of papers dating back into the late 1800's which were primarily descriptive and often displayed either a ecological focus or a geographical focus but seldom incorporated both. Notable exceptions were the works by H.C. Cowles in the late 1800's on Lake Michigan dunes, S.E. Salisbury's 1952 book, *Downs and Dunes*, Derek Ranwell's studies in the 1950's on dunes in the UK, especially at Newborough Warren, Anglesey, and J.S. Olson's work on the Great Lakes in the late 1950's, which were pioneering tomes and papers on the interactions between plant growth habits, plant morphology and dune development. By the late 1970's there was also a revolution in geomorphology and a new approach in coastal morphodynamics was proposed by geomorphologist's including Wright and Thom (1977). Wright and Thom (1977) noted that "the morphodynamic approach involves analyses of the character and spatiotemporal variability of coastal environmental conditions, the hydrodynamic and morphodynamic processes of interaction and transformation which operate within the coastal system to produce the observed morphologic patterns and morphologic changes, and the short and long-term evolutionary sequences which ultimately yield the preserved morphologies and stratigraphies, and which progressively alter the dynamic environments and process combinations" (p.415), and that all of these were mutually independent.

My research was therefore informed by the morphodynamic approach, and was driven by a desire to combine ecological studies on pioneer coastal plants (especially the Australian and New Zealand native pioneer dune building plant *Spinifex* species on which there was minimal information in the 1970's), the aerodynamics and boundary layer flow within plant canopies, sediment transport into and across plant canopies, and foredune geomorphology and evolution. In particular, there was also a need to understand how dune morphology was related to factors such as plant density, distribution, form, height, and growth patterns over time. In addition, there was minimal information on how factors such as wind velocity and direction, rate of beach progradation, beach stability, rates of erosion, beach and dune erosion processes, surfzone-beach types and the potential interaction with dunes, and ecological changes through time affected foredune processes and evolution. This theme and studies related to it have informed my primary research interests throughout the past ~30 years.

The first papers in this arena of research relate to basic morphodynamic studies on incipient foredunes in NSW, Australia, and in particular on foredunes covered by the dominant pioneer plant in eastern Australia, *Spinifex sericeus*. However, work in Southern Australia, Victoria and southern Queensland lead me to consider a wider range of other pioneer and intermediate species involved in the initiation and stabilization of incipient foredunes (articles 1 - 3).

Incipient foredunes may be initiated in a number of ways, one of which is by sand deposition within discrete plants or groups of plants. Thus, one of my first studies was to conduct field and wind tunnel research on flow around discrete plants and the resulting nebkha (or nabkha; dune formed within the plant) and shadow dunes (pyramidal dune formed downwind of the plant) that form as sand transport and deposition takes place. The first major publication in 1981 on shadow dunes (Hesp, 1981; article 1) remains one of the definitive papers on this topic. Subsequent papers detailed how the various types of incipient foredunes formed, their morphodynamic evolution, and their characteristic internal structures or stratification (Hesp, 1983, 1984a; articles 2 and 3). Two major review papers on the topic followed, and included new research comprising (i) one of the first coastal field analyses of wind flow within dune plant canopies of varying heights, (ii) a comprehensive compilation of stratification styles in incipient foredunes (Hesp, 1989; article 4), and, (iii) the first major global review on ecological processes and plant adaptations on coastal dunes (Hesp 1991; article 5).

'Beach Ridges' and Foredunes

In Australia there was considerable debate on how so-called 'beach ridges' evolved, and although a series of papers on beach ridge initiation and evolution had appeared in the 1960's, multiple hypotheses on their evolution had been proposed with little resolution (e.g. Davies, 1957, McKenzie, 1958; Bird, 1960). For some in the Australian scientific community, sand 'beach ridges' were likely incipient foredunes and foredunes, but for others they might comprise a beach berm with perhaps a minimal dune cap, or a storm ridge built entirely by waves. Little formal research had been conducted on beach ridges, and no long term topographic surveys, field measurements, or supporting data such as an analysis of internal structures had been published in Australia by the late 1970's, and, in fact, little had been published elsewhere in the world at that time.

A second sub-theme of my research on incipient foredunes therefore lead to studies related to the 'beach ridge' question. These studies aimed at establishing that many *sand* beach ridges (i.e. not ridges formed in sediments coarser than coarse sand) formed on open ocean coasts in Australia were, in fact, incipient foredunes and foredunes, and thus formed by aeolian deposition in plants on the backshore above the high tide line. This work largely disproved a widely held Australian view proposed particularly by Bird (e.g. 1960) that beach ridges were formed by berm formation (Hesp, 1984b; article 6).

Research on barrier evolution in southern Brazil also lead to a re-examination of the evolution of a so-called 'beach ridge' system. Hesp et al., (2005) produces a complete re-evaluation of the dune types comprising the barriers (Hesp et al., 2005; article 7). A subsequent short review of the international literature lead to a paper on a wider range of 'beach ridge' types than those discussed in Hesp (1984b) and a call for redefinition of the terms (Hesp, 2006; article 8).

Established Foredunes – Evolution, Ecology, Dynamics and Management

Incipient foredunes may gradually evolve into larger, more complex dunes with a wider range of plant species, and become established foredunes. My research on incipient foredunes naturally expanded to established foredunes, and while there had been many papers written on established foredunes by the mid-1970's, few incorporated the morphodynamic approach, there had been minimal observations of wind flow over foredunes, few comparisons of foredune development on different beach types (reflective to dissipative) existed, no classification scheme of foredunes existed, and the sedimentary structures had only been observed in very few cases and then principally in highly erosional foredunes, or those formed initially by shadow dune development and later coalescence and merging (e.g. Goldsmith, 1973).

Hesp (1988a; article 9) was the first paper to classify foredunes into morpho-ecological types (thereby combining plant cover and morphological state), examine the various processes operating on those types, and providing key stratification signatures for foredune types. The five foredune types displayed in article 9 was a relatively simple first attempt, and following research on a wider range of dunes and dune processes, the 5-type classification was expanded to include a wider temporal perspective following an invited Binghampton symposium address (Hesp, 2002; article 10). This paper has been widely cited (relative to the small disciplinary field and researchers working in the coastal dune arena), and the model contained therein is now appearing in coastal texts and reviews (e.g. Reed et al., 2011; Davidson-Arnott, 2012; Houser and Ellis, 2013).

Research on wind flow over foredunes using conventional cup anemometry was relatively difficult and restrictive in the 1970's to 1990's. The invention of high response anemometry (particularly sonic anemometers), and devices such as Wenglors (laser particle counters) has meant that measuring 3D wind flow and direction and instantaneous sediment transport over dunes became a reality in the late 1990's to 2000's. In 2000, in collaboration with Dr. Robin Davidson-Arnott (University of Guelph) we initiated a study of wind flow and sediment transport over a large foredune system at Prince Edward Island (PEI), Canada. This project expanded to include three colleagues, namely, Dr.'s Ian Walker (University of Victoria), Dr. Bernard Bauer (University of British Columbia), and Dr. Jeff Ollerhead (Mt Allison University). This group has conducted joint research on flow and sediment transport over the foredune and the adjacent beach at PEI for several years with all contributing to the co-writing of the articles.

Articles 11 to 15 detail various experiments and findings from multiple experiments conducted at PEI and represent significant novel and unique research results including (i) combined 1D, 2D and 3D flow measurements in horizontal and vertical arrays over a vegetated foredune; (ii) the first field study of speed-down within vegetation up a foredune stoss slope, (iii) the first measurements of gale force winds and jets over a foredune, (iv) the first measurements of jet flow structure during changing regional wind speeds, (v) the first measurements of *speed-up* within a vegetation canopy *up* a foredune stoss slope (a fundamentally novel finding; Hesp et al., 2005, article 11), (vi) a significantly improved understanding of the nature of flow steering, and 3D wind flow structure for oblique approach winds (Walker et al., 2006, 2009; articles 12 and 13), (vii) detailed observations of sediment transport and scarp filling during storm conditions, storm surge, and absolute minimal fetch lengths (Hesp et al., 2009, article 14), and (viii) sediment transport via suspension during gale conditions (article 15). A further series of papers (articles 16 to 20) describing sediment transport across the foredune during another storm, offshore, alongshore and onshore flow conditions, and jet flow structures are either recent additions to this body of work, or forthcoming (Bauer et al., 2012; Davidson-Arnott et al., 2012; Chapman et al., 2012, in press; Hesp et al., in press; Articles 16-20) .

THEME 2: BEACH SEDIMENT TRANSPORT

The links between beach fetch, wind direction, beach sand transport, sediment supply variations, beach surface moisture and dune formation, and a greater understanding of beach-dune interactions have been investigated in Articles 21 to 26, and Sherman et al. (2006). In these, my participation has principally been one of assisting in the field research, and a minor to very minor role in writing the papers.

THEME 3: SURFZONE, BEACH AND DUNE ECOLOGY

While with the Department of Agriculture in Western Australia, I met Dr. Anton McLachlan (at that time in the Department of Ecology at University of Port Elizabeth [UPE]) and we conducted a novel study of faunal dynamics in reflective beach cusps (Mclachlan and Hesp, 1984a; article 27). This was followed by a study of surfzone diatoms in Australia leading to the first citing of phytoplankton on southeast Australian coast surfzones (McLachlan and Hesp, 1984b; article 28). Hesp and Short (1999; article 29) provided a review of surfzone fauna and relationships to surfzone morphodynamic types based largely on the works of Mclachlan. In 1985 I held a visiting fellowship at UPE and we carried out a pioneer study of the fauna resident in nebkha (or nabkha - isolated or discrete dunes formed within a plant or group of plants) of varying sizes, and formed within various plant species (Hesp and Mclachlan, 2000; article 30).

THEME 4: COASTAL AND DESERT DUNE MORPHODYNAMICS

Blowouts

Apart from a pioneer study by Landsberg and Riley (1943), there had been few studies of the sediment transport and aerodynamics in blowouts, particularly trough blowouts, up until the late 1980's with the notable exceptions of, for example, Hails and Bennett (1981), and Gares and Nordstrom (1987). Thus, the 1990 review of erosional dune processes (Carter et al., 1990; article 31) including my work on trough blowout dynamics, and foredune scarp erosion and post-scarp fill processes was the first review of its kind. Following this, Hesp and Hyde (1996; article 32) published the first detailed study of flow within a trough blowout including an analysis of the 2D and 3D flow structure, and the evidence of topographically forced jet flow within the narrow, constricted, deep morphology. Subsequently, Hesp and Pringle (2001; article 33) published the first study of topographic steering of flow within a small trough blowout, demonstrating that winds from almost any onshore to alongshore direction would be re-directed up the blowout due to the steering of the wind flow by the trough topography. In 2002, Hesp (article 10 cited above) reviewed the then current knowledge on blowout types, initiation, processes and evolution. Recently, Hesp and Walker (2012; article 34) reported the results of a study conducted in a deep bowl blowout at PEI, and described for the first time with UVW data, the complex 3-D flow patterns and sediment transport within this type of blowout.

Transgressive Dunefields

While transgressive dunefields were described in the literature going back into medieval times primarily due to their mobile nature and impact on settlements, farming and forestry, it was the pioneer work of Cooper (1958, 1967) which comprehensively described the geomorphology, dynamics and landforms of such coastal dunefields. Very few articles were published on transgressive dunefields following these works, and Hesp and Thom (1990) provides the first, and currently only review of coastal transgressive dunefields in the literature (Hesp and Thom, 1990; article 35).

In 2001 I was invited to southern Brazil by Dr. Sergio Dillenburg (CECO, UFRGS) to give a keynote address at the national ABEQUA conference. This began a long term collaboration with Dr.'s Dillenburg, Barboza, Gruber, Tomazelli, Martinho, Miot da Silva, Giannini, Angulo, Calliari and others.

Southern Brazil, and in particular, the coasts of the States of Santa Catarina and Rio Grande do Sul are dominated by transgressive dunefields. With the colleagues mentioned above, we investigated a range of transgressive dunefield barriers along the coast examining landform units and facies types (Martinho et al., 2006; article 36), barrier morphology and relationships with sea level change (Hesp et al., 2007; article 37), the nature of regional windfield dynamics and dunefield development (Hesp et al., 2007; article 38), barrier dynamics (retrograding, prograding and stationary), transgressive dunefield types (Martinho et al., 2008; article 39), and historical changes in transgressive dunefields (Martinho et al., 2010; article 40; Miot da Silva and Hesp, in press, 2013).

During this period, I also conducted a study of the climbing dunes (and foredunes) at Castlepoint, east coast, North Island, New Zealand, and provided an explanation of how climbing dunes are formed and maintained despite being on a leeward coast with dominant offshore winds (Hesp, 2005; article 41). With colleagues from Mexico we published the first account of transgressive dunefield landform units and vegetation associations in a Veracruz dunefield (Hesp et al., 2011; article 42).

In 2008 I discovered that trailing ridges were quite commonly formed from the margins of transverse dunes in transgressive dunefields, in similarity to trailing ridges formed during parabolic dune formation. Hesp and Martinez (2008; article 43) details this discovery and the first account of vegetation changes and diversity along one transverse dune trailing ridge in Veracruz State, Mexico.

Coastal/Desert and Planetary Dunes

Transgressive dunefields dominate the southern African south and west coasts, yet were little studied at the time I visited in 1985. At a time when there were also very few studies of the morphodynamics of transverse dunes (see Walker and Hesp review, 2013 [article 54]), I lead a study of wind flow and sediment transport over a transverse dune (Hesp et al., 1989; article 44).

In 1986 and 1988 I held Australian Academy of Science/Academia Sinica grants to work in China. On the first trip, Dr.'s Robert Hyde, Qian Zhengyu and I examined linear dunes in the desert near Golmud (or Ger-emu on some maps), western China. This work lead to the significant discovery that linear dunes can migrate laterally, whilst also maintaining downwind extension (Hesp et al, 1989; article 45).

In 1989 I held a visiting fellowship at the Desert Ecological Research Station (DERU) in Gobabeb, SWA/Namibia. During that period, in collaboration with Steven Freyberger, we conducted a study of granule ripples (Fryberger et al, 1992; article 46). I also carried out a study of barchan dune morphometrics. At that time it had long been established that a linear relationship existed between barchan height and width between the wings or horns, but an explanation had never been presented as to why this was the case. Hesp and Hastings (1998; article 47) provided the first elucidation of how the 3-D flow over a barchan constantly shaped the dune into a near-perfect aerodynamic shape, minimizing drag, and maintaining a mean side slope angle of 11^0.

In 1991-1992 I held a research fellow position at the University of Sydney, and primarily worked on co-writing and editing the 'Myall lakes monograph' (Thom et al., 1992), and compiling and editing a global change research strategy for the Australian Academy of Science (Thom and Hesp, 1992). In addition, based on the data presented in Thom et al. (1992), I wrote the draft of a paper detailing the reworking of Last Interglacial coastal dunes by glacial winds in NSW (Thom et al., 1994; article 48).

In 1995-1996 I taught for a short period at the University of Amsterdam. Dr. Bas Arens and I spent some time on the northern barrier islands and published the first observations of crescentic dunes migrating over frozen beaches during very strong winds (Hesp and Arens, 1997; article 49).

In 2011, David Rubin and I revisited our 1988 Chinese data on linear dunes and presented an entirely different argument than those commonly proposed for the development and nature of linear dunes on Titan, one of Saturn's moons (Rubin and Hesp, 2011; article 50). In this case we argued that the dunes on Titan are linear forms despite a wind regime that should produce transverse forms because the dunes are sticky (due to the presence of tholins), in similarity to the dunes near Golmud, China (sticky due to the presence of clays and salts).

Coastal Dune Systems

In the past 30 years to 2012 my colleagues and I have been asked to write reviews of coastal dune systems, geomorphology and morphodynamics. Some of these are presented in articles 4, 5, 10 and 35. More recent articles include a review and comparison of dunes in tropical versus temperate regions (Hesp., 2004; article 51), disturbance in coastal dune systems (Hesp and Martinez, 2007; article 52), a global review of dune coasts (Hesp, 2011), a photo-essay of dunes of the world (Hesp and Walker, 2013; article 53), a review of airflow over dunes (Walker and Hesp, 2013; article 54), and a review of coherent flow structures in aeolian geomorphology (Bauer et al., in press).

THEME 5: QUATERNARY EVOLUTION OF COASTS

Since dunefields commonly form the surficial or subaerial deposits of barrier systems, I have had a keen interest in understanding barrier evolution and Holocene sea levels and climate changes. I studied palaeo-estuarine deposits during my Master's thesis research (Hesp and Shepherd, 1978), and continued somewhat similar studies on the estuaries of Western Australia during my 'post-doctoral' time[1] at UWA (Hesp, 1984; Hodgkin and Hesp, 1998; article 55).

In 1997, my colleagues at Singapore and I published the first Holocene sea level curve for the region (Hesp et al., 1997; article 56). In collaboration with Dr. Andy Short, I co-wrote several chapters for his edited book on Beach and Shoreface Morphodynamics including articles on barrier morphodynamics (Hesp and Short, 1999, article 57), beach and dune stratification (Short and Hesp, 1999), beach ecology (Hesp and Short, 1999), and the backshore and beyond (Hesp, 1999; article 58).

In 1995 I joined the Department of Geography in the School of People, Environment and Planning at Massey University and with Dr.'s Mike Shepherd and Kevin Parnell reviewed the recent literature on NZ coastal geomorphology (Hesp et al., 1999), and conducted a review of the nearby Manawatu dunefield (Hesp, 2001; article 59). Dr. Mike Shepherd and I subsequently wrote a review of NZ coastal barriers (Shepherd and Hesp, 2003; article 60).

My research in southern Brazil was also concerned with barrier evolution and stratigraphy and with colleagues there we produced papers on the stratigraphy and evolution of various

[1] *It was not strictly a post-doc since I did not have my Ph.D. at the time.*

dunefields and barrier systems (Dillenburg et al., 2006, article 61; Barboza et al., 2009, article 62). This work lead to the development of the first book describing the Holocene geology and geomorphology of the entire Brazil coastal barrier systems and examples are included in Hesp et al., 2009 (article 63), and Dillenburg and Hesp, 2009 (article 64) (see also Hesp et al., 2009a and b, and Dillenburg et al, 2009). This research on southern Brazilian barrier systems continues to this day (e.g. Martinho et al., 2009, article 65; Barboza et al., 2011, article 66; Dillenburg et al., 2011, article 67; Miot da Silva and Hesp, 2013).

THEME 6: SURFZONE-BEACH-DUNE INTERACTIONS MODELS

In the period from 1970 to 1980, the initial, incomplete surfzone-beach models of e.g. Sonu (1973) were expanded by Chappell and Eliot (1979), Short (1979), and Wright et al. (1979). Short and Wright eventually combined their work into a comprehensive, robust model detailing micro-tidal surfzone-beach characteristics and types (e.g. Wright and Short, 1984).

During my Ph.D., I began to wonder how foredune building, formation and size might be connected, if at all, to surfzone-beach types. Once it became apparent from the Short and Wright surfzone-beach model that beach widths, mobility (or degree of change), and morphology were strongly related to surfzone type, I theorized that the beach could be perhaps connected to the foredune, since the volume of sediment delivered to a foredune should be related not only to beach fetch (or width of dry beach), but also to beach slope and morphological variability. In 1978, I carried out some measurements of wind flow over varying beach morphologies ranging from reflective to dissipative in order to examine the effect of morphological changes on wind flow and potential aeolian sand transport. Following this I gathered data on the heights and volumes of foredunes formed on different beach types to prove a correlation between increasing foredune height and volume and increasing beach dissipativeness. This lead to the development of the 'wave-beach-dune interaction model', the basics of which constituted the final chapter of my Ph.D. (Hesp, 1982). The model was extended past the foredune to include all coastal dune types.

While working with Dr. Andrew Short in SE South Australia (Short and Hesp, 1979), I related the elements of the model to him. I was subsequently presented with a draft paper of my model, which despite my objections was published as Short and Hesp (1982; article 68). In the following years, I conducted experiments measuring salt spray aerosol loads from surfzones of different types and linked salt spray loads and sand transport to foredune ecological states, particularly vegetation zonation and species richness (Hesp, 1988b; article 69). This paper was the first to measure salt spray loads off varying surfzone-beach types, and relate salt aerosol loads to foredune vegetation characteristics.

Miot da Silva et al. (2008; article 70) and Miot da Silva and Hesp (2010; article 71) applied the model to southern Brazilian beaches, providing supporting data on foredune dynamics and vegetation diversity, and the relationships between surfzone-beach type, wave and wind driven sediment transport, foredune and barrier dunefield development.

This model has become one of the more cited models in the coastal geomorphology literature (see citations with articles list below). Apart from Psuty's (1988; 2008) model which has only sediment supply as *the* factor driving foredune morphology, and Sherman and Bauer's (1993) extension of that model, the wave-beach-dune model is still the only model attempting to relate surfzone-beach types to dune morphodynamics and Holocene barrier evolution (see papers and reviews by e.g. Houser, 2009; Houser and Ellis, 2013; Reed et al., 2009; Davidson-Arnott, 2009; Hesp, 2012).

THEME 7: COASTAL DUNE ARCHAEOLOGY

I developed an interest in coastal archaeology after finding artifacts in the base of deflation basins in blowouts in Western Australia. Following a torrential rainstorm on Rottnest Island in 1993, Dr. Charlie Dortch (Western Australian Museum) initially, and subsequently, he and I found artifacts and potential artifacts that, while disputed, may be some of the oldest Aboriginal sites in Australia (Dortch and Hesp, 1994, article 72; Hesp et al., 1999 article 73). In 2008 I assisted Dr. Jonathan Haws (University of Louisville) and Dr. Michael Benedetti (University North Carolina, Wilmington) in examining coastal beach and dune deposits associated with Neanderthal archaeological sites in Portugal (Benedetti et al., 2009; Haws et al., 2010). More recently, I lead a team which examined several underwater sites in the Gulf of Mexico searching for evidence of PalaeoIndian occupation (Evans et al, submitted) and which also lead to the significant discovery of hornwort pollen associated with one of the sites (Warny et al., 2012). I was also involved in research on several shipwrecks in the Gulf of Mexico (Evans et al., in press), and this work received a Federal (USA Dept. of the Interior) award (see Appendix 1).

THEME 8: COASTAL MANAGEMENT

In 1982 I joined the coastal section of the Western Australia Department of Agriculture and was charged with conducting geomorphological and ecological surveys of coastal areas, producing land management plans for coastal areas subject to development plans, and advising on planning issues. At the time, little was known of the ecology of the NW regions of Western Australia and as a result we conducted a survey of the coastal flora and geomorphology of the Pilbara region (Craig et al., 1983). I also lead a group which produced the first land resource survey of Rottnest Island (Hesp et al., 1984), and later was a member of a team that produced a comprehensive management plan for the Island (RIMPG, 1985). I also co-wrote management plans for various regions in Western Australia (e.g. Wells and Hesp, 1983; Hesp and Morrissey, 1984; Hesp and Curry, 1985).

In the period 1992 to 1993 I worked on Rottnest Island as the environmental manager and with colleagues directed and carried out several investigations relating to management issues on the Island. These studies included an analysis of the impacts of boat moorings on seagrass beds (Hastings et al., 1995a; article 74; Hastings et al., 1995b). In 1993 I joined the Department of Geography at the National University of Singapore (NUS), and following earlier work conducted at Geomarine P/L in 1990 – 1991, collaborated with Dr. Michael Hilton (then NUS, now University of Otago) on a paper reviewing the evidence for determining the outer limits of the surfzone-nearshore system, and elucidating how this data might be used to better manage underwater dredging and sand extraction activities (Hilton and Hesp, 1996; article 75). While at NUS I also produced one of the first reviews of the Singapore Government's E.I.A. process (Hesp, 1996; article 76).

In 2009 I lead a group of Louisiana State University students in a study of the effects of trampling on parabolic dune vegetation (Hesp et al., 2010; article 77). In addition, in 2013, Dr. Marisa Martinez, Dr. Juan Gallego-Fernandez and I completed a edited book on coastal dune restoration processes, techniques, and methods (Martinez et al., 2013). Two chapters from this work are presented as examples from the book (Hesp and Hilton, 2013; article 78; Martinez et al., 2013; article 79).

THEME 9: COASTAL EDUCATION

Partly due to my father's beliefs that most (if not all) research conducted by academics was largely pointless or useless, I have always had a keen interest in providing educational products and information on, and practical applications of my research. To this end I mapped the coastal landforms of the entire Western Australian coast and co-produced a poster map detailing the various WA coastal landforms and climatic and coastal data (Hesp and Chape, 1984). I have produced a booklet on coastal dunes (Hesp, 2000), and co-wrote with Dr. Karen Bryan (University of Waikato) a CD on NZ sandy coasts (published as Payne et al., 2003). Copies of the booklet and CD went to every High School in NZ. I have also edited and written articles for the NZ edition (Hesp, 1999a; 2000) and Australian edition (1999b) of the Geographica Atlas, and carried out all the coastal dune mapping and descriptions of the coastal dunes of Veracruz State (with Dr. Marisa Martinez) for the Atlas of Veracruz coastal dunes and mangroves (Lopez-Portillo et al., 2011). In addition, I have co-written two articles for the Nature Education on-line volume (Sloss et al., 2000a, b).

THEME 10: FUN

It has always been my belief that if possible, and when appropriate, the use of humour to educate is an essential ingredient in teaching and, occasionally (if you can get away with it!), publishing. Hesp (1993; article 80) provides one example.

ARTICLES LIST

Citations (>8) are per May 8th, 2013, Web of Science and Google Scholar

Incipient Foredunes:

1. **Hesp, P.A.,** 1981. The formation of shadow dunes. J. Sedimentary Petrology 51 (1): 101-111. *1st most cited paper in "shadow dunes" in Web of Science, 76 citations Web of Science; 119 in Google Scholar.*
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3. **Hesp, P.A.**, 1984a. Foredune formation in Southeast Australia; In: B.G. Thom (Ed.) Coastal Geomorphology in Australia: 69-97. Academic Press. *25 citations*
4. **Hesp, P.A.,** 1989. A review of biological and geomorphological processes involved in the initiation and development of incipient foredunes. In: Gimingham, C.H., W. Ritchie, B.B. Willetts and A.J. Willis (Editors), Coastal Sand Dunes. Proc. Roy. Soc. Edinburgh Section B (Biol. Sci.) 96: 181-202. *2nd most cited paper in "incipient foredunes" in Web of Science, 52 citations; 79 citations in Google Scholar.*
5. **Hesp, P.A.,** 1991. Ecological processes and plant adaptations on coastal dunes. J. Arid Environments 21: 165-191. *6th most cited article in "Coastal Dunes" in the Web of Science; 117 citations in the Web of Science; 175 citations in Google Scholar.*

Beach Ridge Formation:

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Established Foredunes:

9. **Hesp, P.A.,** 1988a. Morphology, dynamics and internal stratification of some established foredunes in southeast Australia. Sedimentary Geology Special Issue: Aeolian Sediments 55: 17-41. *2nd most cited paper in "established foredunes in Web of Science, 40 citations*
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11. **Hesp, P.A.**, Walker, I.J., Davidson-Arnott, R.G., Ollerhead, J., 2005. Flow dynamics over a vegetated foredune at Prince Edward Island, Canada. Geomorphology 65: 71-84. *9th most cited article in "foredune" in the Web of Science; 31st most cited article in "Coastal Dunes" in the Web of Science; 52 citations; 64 citations in Google Scholar.*
12. Walker, I., **Hesp, P.A.**, Davidson-Arnott, R.G., and Ollerhead, J., 2006. Topographic steering of alongshore flow over a vegetated foredune: Greenwich dunes, Prince Edward Island, Canada. J. Coastal Research 22 (5): 1278-1291. *24 citations*
13. Walker, I.J., **Hesp, P.A.**, Davidson-Arnott, R.G.D., Bauer, B.O., Namikas, S.L., and Ollerhead, J., 2009. Responses of 3-D flow to variations in the angle of incident wind and profile form of dunes: Greenwich Dunes, Prince Edward Island, Canada. Geomorphology 105 (1-2): 127-138. *14 citations*
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Blowouts:

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42. **Hesp, P.A**., Martinez, M.L., Miot da Silva, G., Rodríguez-Revelo, N., Erika Gutierrez, Adriana Humanes, Daniela Laínez, Irene Montaño, Verónica Palacios, Agustín Quesada, Lorena Storero, Gabriela González Trilla, Carolina Trochine, 2011. Transgressive Dunefield Landforms and Vegetation Associations, Doña Juana, Veracruz, Mexico. Earth Surface Processes and Landforms 36 (3): 15: 285–295.
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