Tetrahedron 67 (2011) 4318–4326

Contents lists available at ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

C–H amination/cyclocarbonylation of allene carbamates: a versatile platform for the synthesis of α,β-unsaturated γ-lactams

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ARTICLE INFO

Article history:
Received 17 January 2011
Received in revised form 5 March 2011
Accepted 9 March 2011
Available online 16 March 2011

Keywords:
C–H amination
Rh catalysis
Allenes
Cyclocarbonylation
γ-Lactams

ABSTRACT

Despite their utility as building blocks for the construction of a variety of nitrogen-containing heterocyclic scaffolds, the preparation of allenic amines **2** via the direct C–H amination of allenes of the general structure **1** has not been well-explored. In this report, we describe our preliminary studies on the factors that control the chemoselectivity of Rh-catalyzed aminations of allenes to give either bicyclic methylene aziridines or the desired allenic amines **2**. Additionally, the conversion of selected allenic amines to α,β-unsaturated γ-lactam scaffolds via a facile $Ru_3(CO)_{12}$ catalyzed cyclocarbonylation is described.

1. Introduction

The amination of benzylic and allylic C–H bonds is an active area of research; recently, much progress has been made in designing catalysts to functionalize these bonds under mild conditions, especially in enantioenriched form.[1] Surprisingly, little effort has been devoted toward the analogous C–H amination reactions of allenes, despite the potential of these motifs as convenient building blocks for the construction of nitrogen-containing heterocycles (Fig. 1).[2–11] The majority of the methods for constructing allenic amines involve transformations of propargyl amines, which limits the scope of the targets that can be accessed.[3,12–14] Conversely, the amination of an allenic C–H bond (as in **1**) allows for completely substituted allenes to be utilized as substrates and requires only a simple alcohol handle to install the necessary nitrene precursor. The stereochemistry set at R^3 of **1** is maintained in the C–H amination step and can be used to direct further functionalization of the allenic amine products.[2b,15]

One reason that reports describing the intramolecular amination of allenes may be lacking is that allene aziridination is expected to compete (Scheme 1, **4a** vs **4b**). Certainly, the chemoselectivity in intramolecular allylic aminations of acyclic substrates has been demonstrated to be unpredictable.[15,16] Du Bois has reported surprising chemoselectivity in allylic C–H bond insertions of homoallyl sulfamates using a Rh_2(*S*-nap)$_4$ catalyst, although the reasons for this selectivity are not well-understood.[15] We observed a similar effect in our early studies directed toward new, efficient methods for the stereoselective functionalization of all three carbons of an allene.[17] Eventually, we found conditions that chemoselectively promote allene aziridination to the bicyclic methylene aziridine (MA) **4** over the competing C–H amination to **5**. However, in order to facilitate the development of multi-component reactions that utilize allene aziridination as a key step, we needed a better understanding of the factors that control chemoselectivity for the C–H amination. In this paper, we report our preliminary results directed toward favoring allene C–H amination by varying the nitrene precursor, the length and substitution pattern of the tether and the choice of catalyst/oxidant. Additionally, we demonstrate the allenic amine products can be easily transformed via Ru-catalyzed cyclocarbonylation into α,β-unsaturated γ-lactams, a motif found in a number of structurally and biologically interesting natural products (Fig. 3).

2. Results and discussion

In our studies on the synthesis and reactivity of bicyclic methylene aziridines, we found several factors that increased the amount of allene aziridination over C–H amination (Fig. 2).[17] For example, the use of sulfamates as nitrene precursors increased the amounts of MA compared to the use of carbamates as nitrene precursors, giving only products resulting from **5** (Fig. 2, compare to Scheme 1, condition A). Shortening the tether length between the allene and the nitrene precursor completely shut down the C–H

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doi:10.1016/j.tet.2011.03.026

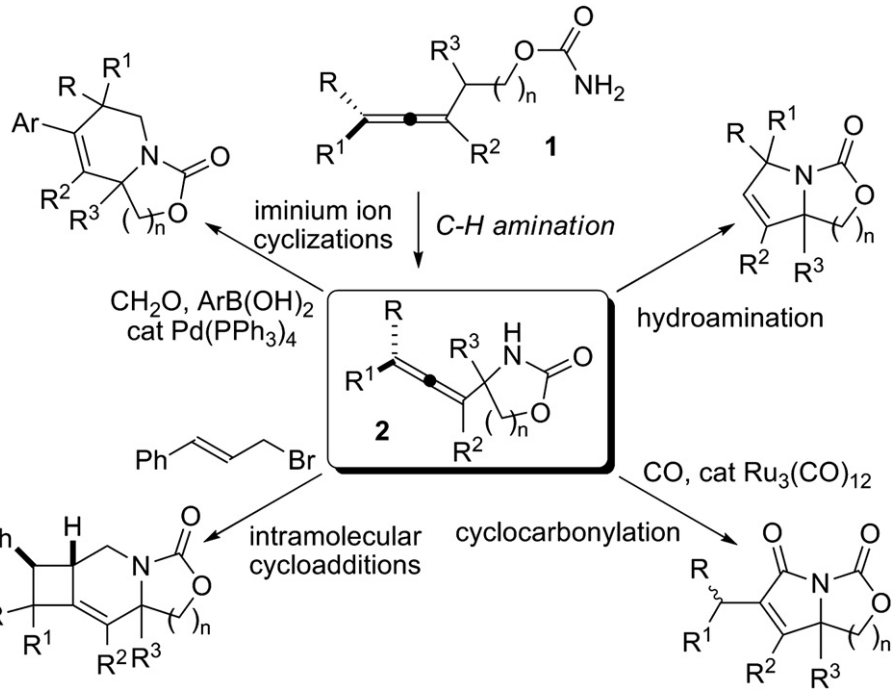
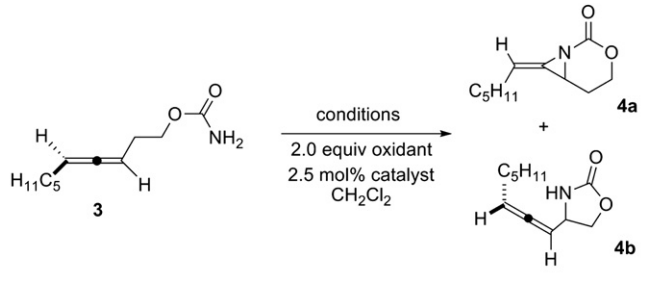


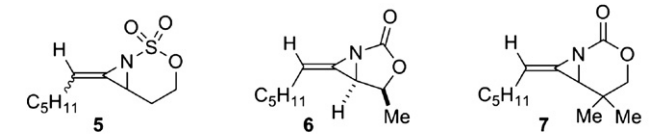
Fig. 1. Potential transformations of allenic amines to nitrogen-containing heterocycles.



Conditions	4a	4b
A: $Rh_2(esp)_2$, $PhI(OAc)_2$, 2.6 equiv MgO, 35 °C	46% *E*:*Z* 1.5:1	44%
B: $Rh_2(esp)_2$, $PhI(OPiv)_2$, 2.6 equiv MgO, 35 °C	42% *E*:*Z* 4.1:1	45%
C: $Rh_2(esp)_2$, PhIO, 4 A MS, rt	66% *E*:*Z* 3:1	16%
D: $Rh_2(TPA)_4$, PhIO, 4 A MS, rt	80% *E*:*Z* 4:1	15%

esp = α, α, α', α'-tetramethyl-1,3-benzenedipropionate
TPA = triphenylacetate

Scheme 1. Chemoselectivity in intramolecular allene aziridination and C–H amination.



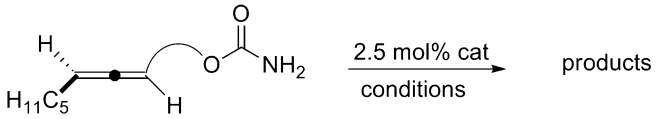
[a]See Scheme 1 for reaction conditions.

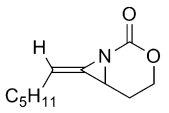
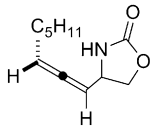
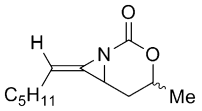
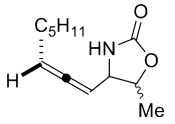
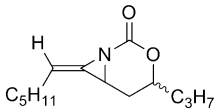
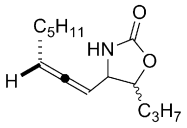
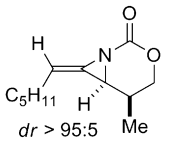
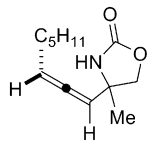
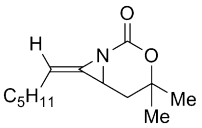
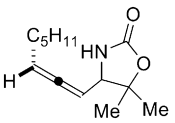
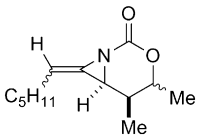
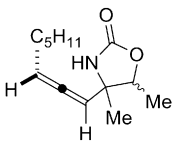
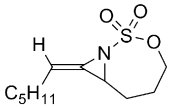
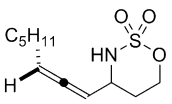
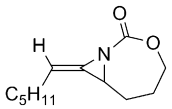
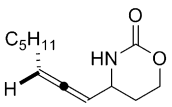
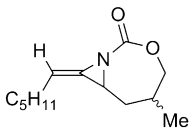
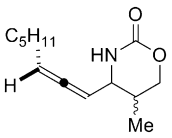
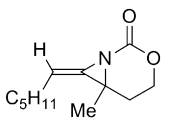
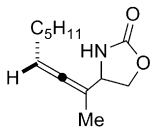
Fig. 2. Promotion of allene aziridination.

amination and gave only **6** in good yield. As expected, replacing susceptible C–H bonds with methyl groups was also an effective strategy, giving bicyclic methylene aziridine **7** in 94% yield. However, without the mitigating factors present in Fig. 2, C–H amination was a competing process (Scheme 1). The identity of the catalyst and the oxidant played a role in determining the chemoselectivity of the reaction, although the reasons for this are not well-understood at this time.[15]

In an effort to better probe the effect of the length and substitution pattern of the allene on the reaction, a series of allenic carbamates were prepared and subjected to Rh catalysis in the presence of a hypervalent iodine oxidant (Table 1). The maximum amount of C–H amination product for a two-carbon unbranched tether between the allene and the carbamate (**4b**, 45%, entry 1) was achieved using $Rh_2(esp)_2$ as the catalyst in the presence of $PhI(OPiv)_2$ as the oxidant. The addition of a methyl group to the carbon β to the allene (entry 2) resulted in greater amounts of the aziridination product **8a** as compared to **8b** (**8b**/**8a** 0.7:1). A larger propyl group (entry 3) increased the amination–aziridination ratio only slightly to (**9b**/**9a** 0.9:1). Increasing the electron density of the allenic C–H bond by placing a methyl group α to the allene (entry 4) improved the chemoselectivity of **10b**/**10a** to 2.7:1. Surprisingly, increasing the steric bulk (and the presumed Thorpe–Ingold effect) at the carbon β to the allene further by installation of a *gem*-dimethyl group (entry 5) gave predominantly C–H amination product **11b** in high yields (**11b**/**11a** 7.2:1) using $Rh_2(esp)_2$/$PhI(OPiv)_2$. The use of Rh_2TPA_4/PhIO (TPA=triphenylacetate) more than doubled the selectivity of **11b**/**11a** to 16.8:1. The respective effects of the catalyst ligands and the oxidant on the chemoselectivity are not yet clear, but PhIO was a superior oxidant in terms of reaction rate, extent of conversion and maintenance of catalyst activity. The placement of methyl groups at the carbons α and β to the allene (entry 6) was also effective at promoting amination over aziridination in a ratio of 5.1:1. The dr set in the formation of the allene carbamate substrate was maintained in **12a** and **12b**. Increasing the length of the tether between the allene and the nitrene precursor to three carbons (entry 7) might be expected to favor the C–H amination product **13b**, as making a six-membered ring should be favored over the 7-membered one.[15] This was true with $Rh_2(esp)_2$ as the catalyst and $PhI(OAc)_2$ as the oxidant, but the use of Rh_2TPA_4 with the less soluble oxidant PhIO gave almost exclusively the methylene aziridine **13a** in good yield.[16] Switching to a carbamate precursor using a three-carbon tether (entry 8) slowed the reaction significantly and only a 9% yield of the amination product **14b** was

Table 1
Intramolecular C–H amination of allenic carbamates



Entry	Conditions[a]	Products	
1	B: 42% **4a** *E*/*Z* 1.5:1 45% **4b**		
2	B[b]: 39% **8a** (*E*/*Z* 2.2:1) 29% **8b** dr 2:1		
3	B[b]: 34% **9a** (*E*/*Z* 2.5:1 30% **9b** dr 2.2:1)		
4	B: 21% **10a** *E*/*Z* 3:1 57% **10b**		
5	B: 10% **11a**; 72% **11b** D: 5% **11a**; 84% **11b**		
6	C: 12% **12a**; 61% **12b** dr 1.3:1		
7	B[b]: 35% **13a**; 44% **13b** D: 82% **13a**; 8% **13b**		
8	B: 0% **14a**; 9% **14b** C: 0% **14a**; 33% **14b**		
9	C: 0% **15a** 70% **15b** dr 2:1		
10	C: 18% **16a**; 28% **16b**		

[a] See Scheme 1 for conditions.
[b] $PhI(OAc)_2$ was used as the oxidant.

obtained, with no evidence of the aziridine **14a**. However, incorporation of a single methyl group into the tether at the carbon β to the allene (entry 9) not only completely shut down the aziridination, but greatly increased the rate of the reaction to give **15b** in 70% yield as a 2:1 mixture of diastereomers. Finally, increasing the substitution of the allene resulted in only a 1.6:1 ratio of **16b**/**16a**, perhaps due to increased electron density at the proximal allene double bond. Modifications to the tether are expected to significantly increase the chemoselectivity.

Based on the preliminary data in Table 1, the following conclusions about control of the aziridination/C–H amination can be made. First, although sulfamates are significantly more reactive than carbamates, aziridination is the favored pathway, even when the tether between the allene and the nitrene precursor is such that a seven-membered ring results from aziridination, rather than the six-membered ring that would arise from C–H amination.[15] Second, the placement of *one* alkyl group at the carbon β to the allene does not help increase C–H amination, but *two* alkyl groups give almost exclusively amination, presumably due to the conformational effects in the transition state.[1n,15] Third, the placement of an alkyl group at the carbon α to the allene increases the amount of amination, but still gives substantial amounts of methylene aziridine. Groups that increase the electron density of the allylic C–H bond further would be expected to give greater amounts of amination products. Fourth, placement of an alkyl group at both α and β carbons exhibit a synergistic effect as compared to just one group at either the α or β carbon. Fifth, for tethers that contain more than two carbons between the allene and the carbamate, branching appears to promote reasonable conversion and only the amination product is observed. Lastly, a 1,1′,3-trisubstituted allene carbamate gave decreased yields of products and did not improve the C–H amination/aziridination ratio. Thus, substitution in the tether appears to be the most viable option for favoring allenic amine formation.

With our success in generating synthetically useful quantities of allenic amines via C–H amination, we wanted to demonstrate the utility of the allenic amine products in the preparation of highly substituted α,β-unsaturated γ-lactams. Highly substituted γ-lactams are common motifs in a variety of structurally and biologically interesting natural products (Fig. 3) and a predictable, general method to access these scaffolds would be valuable. The cyclocarbonylation of acyclic allenic amines has been previously described, but the scope of the reaction was quite limited and only sparsely substituted products were obtained.[8,11,12] In addition, the bicyclic nature of the unsaturated lactam produced as a result of cyclocarbonylation (Scheme 2) means that the stereochemistry of R^3 group could be used to effectively dictate the stereochemistry of subsequent manipulations of these scaffolds.[18]

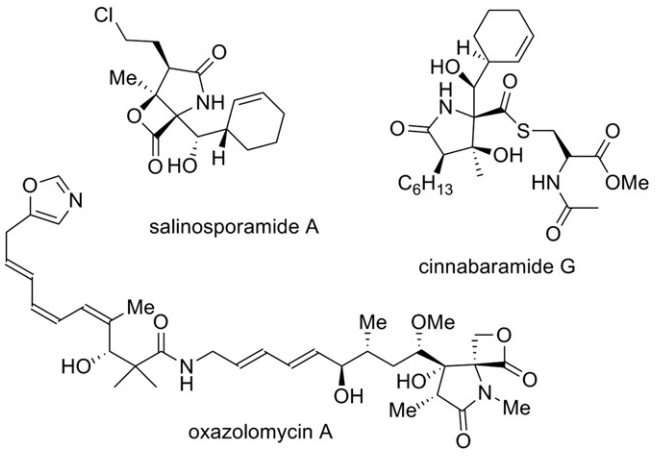
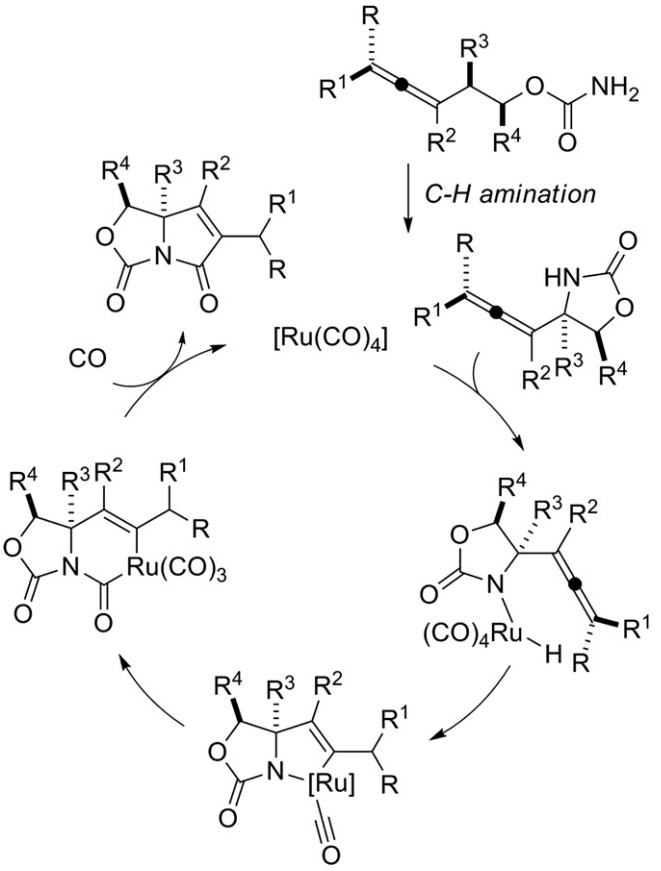


Fig. 3. γ-Lactam containing natural products.

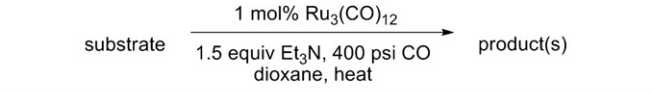


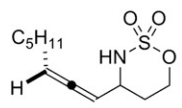
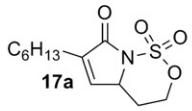
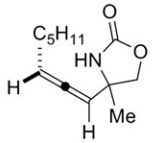
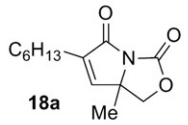
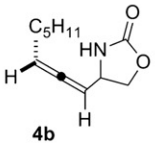
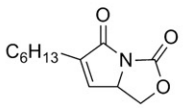
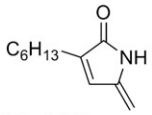
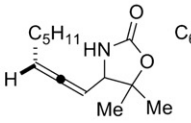
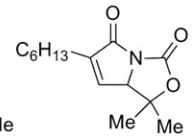
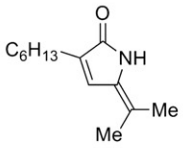
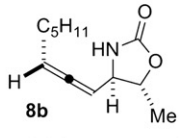
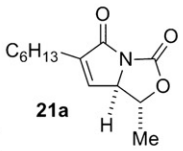
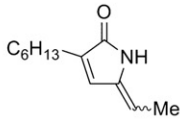
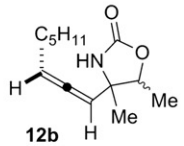
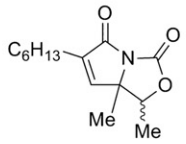
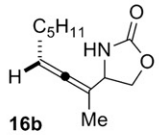
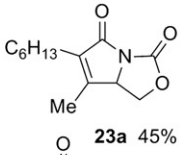
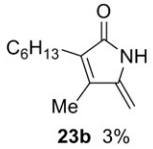
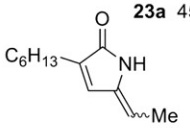
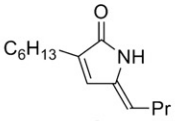
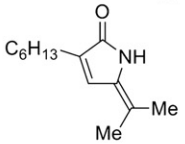
Scheme 2. C–H amination/cyclocarbonylation of allenic carbamates as a route to γ-substituted lactams.

A variety of metal carbonyls were explored to promote the reaction and $Ru_3(CO)_{12}$ was found to be most effective. Ligands for Ru, including Ar/BIAN (BIAN=bis(aryl)acenaphthenequinonediimine) were briefly explored, but did not improve the reaction as compared to $Ru_3(CO)_{12}$ alone.[19] Optimization studies showed that as little as 1 mol % of the catalyst could be utilized, with an optimal temperature of 80 °C. Higher temperatures resulted in a greater overall conversion, but also greater amounts of decarboxylated by-products (see Table 2). At least 1 equiv of a tertiary amine base was necessary to promote good conversion.

Table 2 illustrates results for the cyclocarbonylation of selected allenic amines. The decreased nucleophilicity of the sulfamate, as well as the formation of a six-membered ring (Table 2, entry 1) resulted in a lower yield of **17a** as compared to the carbamates. The value of **17a** as a scaffold for further transformation is recognized and efforts will continue to utilize sulfamates as substrates for the cyclocarbonylation. Carbamates performed much better, although decarboxylation was sometimes a competing side reaction. When the absence of a proton at the ring juncture prevented this side reaction (entry 2), **18a** was formed in a good 78% yield. Cyclocarbonylated products **19a** and **20a** (entries 3–4) were formed in moderate yields, with decarboxylation occurring to give the by-products **19b** and **20b**. Interestingly, subjecting a mixture of diastereomers (**8b**, dr 2:1 in favor of the *trans* isomer) to the cyclocarbonylation at 80 °C led to only one diastereomer of the product **21a**, identified as the *trans* isomer by NOE and ^{1}H NMR coupling constants. The 2.1:1 ratio of **21a**:**21b**, compared to the 2:1 dr of **8b** suggested that the *cis* cyclocarbonylated product undergoes decarboxylation more rapidly than the *trans*. However, increasing the reaction temperature obviated this reactivity difference and promoted in situ decarboxylation to generate **20b**, **21b**

Table 2
Cyclocarbonylations to α,β-unsaturated γ-lactams



Entry[a]	Substrate	Product	Yield
1		**13b**  **17a**	24%
2		**10b**  **18a**	78%
3	 **4b**	 **19a** 57%  **19b** 27%	
4	 **11b**	 **20a** 56% (60%)[b]  **20b** 12% (36%)[b]	
5	 **8b**	 **21a**  **21b** 25% (2:1 *E*:*Z*)	
	dr 2:1 (major shown)	53% *dr* > 95:5	
6	 **12b**	 **22a**	97% *dr* 1.3:1
7	 **16b**	 **23a** 45%  **23b** 3%	
8[c]	**8b**	 **21b**	91% (10:1 *E*:*Z*)
9[c]	**9b**	 **24b**	70% (*E* only)
10[c]	**11b**	 **20b**	88%

[a] $Ru_3(CO)12$ (1–2 mol %), 1.5 equiv Et_3N, 400 psi CO, dioxane, 80 °C.
[b] 100 °C.
[c] 500 psi CO, 100 °C.

and **24b** in excellent yields (entries 8–10), with the *E* isomer as the major product. The 1,1′,3-trisubstituted allenic amine **16b** gave **23a** as the major product (entry 7). Although by-products from double bond isomerization were observed, to our knowledge, this represents the first example of a Ru-catalyzed cyclocarbonylation of an allene of this substitution pattern. This bodes well for the continued development of these reactions for the eventual preparation of fully substituted γ-lactam scaffolds.

3. Conclusion

In conclusion, we have demonstrated that control of the catalyst, oxidant and substrate can influence the ratio of C–H amination to aziridination in a series of allene carbamates. The resulting products readily undergo cyclocarbonylation to yield scaffolds for further elaboration into highly substituted γ-lactams. Future work is directed toward the development of new catalysts that can increase the chemoselectivity of the C–H amination over aziridination, probing the effect of the oxidant on the reaction outcome and asymmetric C–H amination of allenes. Continued exploration of cyclocarbonylations using enantioenriched substrates and the elaboration of the resultant motifs into γ-lactam containing natural products are also underway and will be reported in due course.

4. Experimental section

4.1. General

All glassware was either oven-dried overnight at 130 °C or flame-dried under a stream of dry nitrogen prior to use. Unless otherwise specified, reagents were used as obtained from the vendor without further purification. Tetrahydrofuran and diethyl ether were freshly distilled from purple Na/benzophenone ketyl. Dichloromethane, acetonitrile, and toluene were dried over CaH_2 and freshly distilled prior to use. Air- and moisture-sensitive reactions were performed either in a Braun LabStar glovebox under an atmosphere of nitrogen or using standard Schlenk techniques under an atmosphere of nitrogen. Analytical thin layer chromatography (TLC) was performed utilizing pre-coated silica gel 60 F_{254} plates containing a fluorescent indicator, while preparative chromatography was performed using SilicaFlash P60 silica gel (230–400 mesh) via Still's method.[2] Unless otherwise stated, the mobile phases for column chromatography were mixtures of hexanes/ethyl acetate. Columns were typically run using a gradient method, beginning with 100% hexanes and gradually increasing the polarity using ethyl acetate. Various stains were used to visualize reaction products, including *p*-anisaldehyde, $KMnO_4$, ceric ammonium nitrate, and phosphomolybdic acid in ethanol stain.

^1H NMR and ^{13}C NMR spectra were obtained using Bruker-300, Varian Inova-500, Varian Unity-500 or Varian Inova-600 NMR spectrometers. For ^1H NMR, chemical shifts are reported relative to residual protiated solvent peaks (δ 7.26, 2.49, 7.15, and 4.80 ppm for $CDCl_3$, $(CD_3)_2SO$, C_6D_6, and CD_3OD, respectively). ^{13}C NMR spectra were measured at either 125 MHz or 150 MHz on the same instruments noted above for recording ^1H NMR spectra. Chemical shifts were again reported in accordance to residual protiated solvent peaks (δ 77.0, 39.5, 128.0, and 49.0 ppm for $CDCl_3$, $(CD_3)_2SO$, C_6D_6, and CD_3OD, respectively). IR spectral data were obtained using a Bruker Vector 22 spectrometer using either a thin film or an ATR adapter. Melting points were obtained with a Mel-Temp II (Laboratory Devices, Inc.) melting point apparatus. Accurate mass measurements were acquired at the University of Wisconsin, Madison using a Micromass LCT (electrospray ionization, time-of-flight analyzer or electron impact methods).

The allenic alcohol substrates for the entries in Table 1 were prepared according to literature methods.[17,20]

4.2. General procedures for the C–H amination and aziridination of allenes

General procedure A. The allene carbamate (1.0 mmol, 1.0 equiv) and 10 mL of dry CH_2Cl_2 were added to a dry 50 mL Schlenk flask. The solution was kept under an atmosphere of nitrogen and charged with MgO (2.6 mmol, 2.6 equiv) and $Rh_2(esp)_2$ (0.025 equiv). The resulting blue–green mixture was stirred for 10 min at rt, then $PhI(OAc)_2$ (1.0 mmol, 1.0 equiv) was added, the flask fitted with a reflux condenser and the reaction mixture was heated to 35 °C in an oil bath for 1 h. Two additional 0.164 g (0.5 mmol, 0.5 equiv) portions of $PhI(OAc)_2$ were added at 1 h intervals. The reaction was monitored by TLC until complete (4 h). The heterogeneous mixture was concentrated under reduced pressure and the brick red residue chromatographed on silica gel using a hexanes/EtOAc gradient. Pre-treatment of the silica gel column with 99.5:0.5 hexanes/triethylamine, followed by flushing with four column volumes of hexanes prior to loading the sample often improved the separation and prevented the decomposition of sensitive methylene aziridines.

General procedure B. A dry 50 mL Schlenk flask was charged with allene carbamate **15** (1.0 mmol, 1.0 equiv), followed by 6 mL of dry CH_2Cl_2. The solution was kept under an atmosphere of nitrogen and charged with MgO (2.6 mmol, 2.6 equiv) and Rh_2esp_2 (0.025 equiv). The resulting blue–green mixture was stirred for 10 min at rt, then 0.829 g $PhI(OPiv)_2$ (2.0 mmol) dissolved in 5 mL of dry CH_2Cl_2 was added dropwise over the course of 1.5 h via syringe pump. The flask was fitted with a reflux condenser and heated to 35 °C in an oil bath for 2 h or until TLC indicated the reaction was completed. The heterogeneous mixture was concentrated under reduced pressure and the brick red residue chromatographed on silica gel eluting with a hexanes/EtOAc gradient.

General procedure C. A dry 50 mL Schlenk flask was charged with allene carbamate (1.9 mmol) and 20 mL of dry CH_2Cl_2. The solution was kept under an atmosphere of nitrogen and charged with 4 Å MS (0.925 g) and Rh_2esp_2 (0.047 mmol). The resulting blue–green mixture was stirred for 10 min at rt, then PhIO (3.8 mmol) was added in one portion. The heterogeneous light green suspension was stirred at rt until completed by TLC (usually within 4 h). The resulting mixture was concentrated under reduced pressure, taken up in Et_2O and filtered through a pad of Celite. The filtrate was concentrated under reduced pressure and the brick red residue was chromatographed on SiO_2 gel eluting using a hexanes/EtOAc gradient.

General procedure D. A dry 50 mL Schlenk flask was charged with the allene carbamate (0.37 g, 1.9 mmol) and 19 mL of dry CH_2Cl_2. The solution was kept under an atmosphere of nitrogen and charged with 4 Å MS (0.925 g) and $Rh_2(TPA)_4$ (0.047 mmol). The resulting blue–green mixture was stirred for 10 min at rt, then PhIO (0.826 g, 3.8 mmol) was added in one portion, and the heterogeneous light green suspension was stirred at rt until complete by TLC (usually within 4 h). The resulting mixture was concentrated under reduced pressure, taken up in Et_2O, and filtered through a pad of Celite. The filtrate was concentrated under reduced pressure and the brick red residue was chromatographed on silica gel eluting with a hexanes/EtOAc gradient.

*4.2.1. (7E)-7-Hexylidene-3-oxa-1-azabicyclo[4.1.0]heptan-2-one (**4a**).* The product was obtained using general procedure A in 46% yield after column chromatography as a thick, clear oil. The major isomer had the *E* configuration at the olefin: ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.55 (dd, 1H, J=7.3, 6.8 Hz), 4.50 (dd, 1H, J=11.3, 2.1 Hz), 4.33 (ddd, 1H, J=11.0, 4.0, 2.6 Hz), 3.40 (dd, 1H, J=8.0, 6.5 Hz), 2.34 (m, 2H), 2.13 (ddd, 2H, J=8.5, 7.2, 1.6 Hz), 1.59–1.2 (m, 6H), 0.85 (t, 3H, J=8.0 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ 156.4, 125.5, 103.2, 68.8, 39.5, 31.3, 28.8, 28.2, 24.3, 22.4 14.0. HRMS (ESI) m/z calculated for $[M+H]^+$ 196.1333, found 196.1342.

*4.2.2. 4-(Octa-1,2-dien-1-yl)-1,3-oxazolidin-2-one (**4b**).* The product was obtained using general procedure A in 44% yield as a clear, thick oil. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.01 (br d, 1H, J=7.3 Hz), 5.32 (m, 1H), 5.11 (m, 1H), 4.49 (dd, 1H, J=8.7, 8.2 Hz), 4.32 (dd, 1H, J=13.8, 6.1 Hz), 4.13 (dd, 1H, J=8.4, 5.9 Hz), 1.98 (m, 2H), 1.35–1.26 (br m, 6H), 0.85 (t, 3H, J=6.7 Hz). ^{13}C NMR (75 MHz, $CDCl_3$) δ 203.7, 159.4, 95.4, 95.2, 91.1, 70.2, 52.1, 51.9, 31.1, 28.7, 28.5, 28.3, 28.2, 22.3, 13.9. HRMS (ESI) m/z calculated for $[M+H]^+$ 196.1333, found 196.1339.

*4.2.3. (7E)-7-Hexylidene-4-methyl-3-oxa-1-azabicyclo[4.1.0]heptan-2-one (**8a**).* The product was obtained as a 1.5:1 mixture of *E*/*Z* isomers in 48% yield as a thick, colorless oil using general procedure D. ^{1}H NMR (500 MHz, C_6D_6) δ 5.54 (t, J=6.9 Hz, 0.6H), 5.15 (t, J=7.6 Hz, 0.4H), 3.94 (m, 1H), 2.51–2.77 (m, 2H), 1.94 (app q, J=7.3 Hz, 2H), 1.08–1.36 (m, 7H), 0.86 (t, J=7.1 Hz, 3H), 0.81 (two doublets, J=6.3, 5.9 Hz, 3H total). ^{13}C NMR (125 MHz, C_6D_6) δ 155.5, 155.1, 126.9, 126.5, 102.2, 101.3, 76.2, 75.9, 38.5, 38.4, 31.4, 31.3, 30.7, 30.7, 29.7, 28.8, 28.1, 27.2, 22.5, 22.5, 20.2, 20.1, 13.9, 13.9. HRMS (EI) m/z calculated for $[M+H]^+$ 210.1489, found 210.1482.

*4.2.4. 5-Methyl-4-(octa-1,2-dien-1-yl)-1,3-oxazolidin-2-one (**8b**).* The product was obtained as an inseparable mixture of stereoisomers (~2:1 approximate dr for C–H amination) in 31% as a thick, colorless oil using general procedure D. ^{1}H NMR (500 MHz, C_6D_6) δ 7.22 (br s, 1H), 5.16 (m, 1H), 4.84 (m, 0.6H), 4.74 (m, 0.4H), 4.16 (m, 0.4H), 3.99 (m, 0.6H), 3.67 (m, 0.4H), 3.42 (m, 0.6H), 1.87 (m, 2H), 1.17–1.40 (m, 6H), 0.80–0.98 (overlapping doublets and triplets, 6H). ^{13}C NMR (125 MHz, C_6D_6) δ 204.2, 203.9, 203.9, 159.7, 159.3, 94.7, 94.5, 94.3, 94.2, 91.1, 91.0, 88.5, 78.5, 75.6, 75.5, 59.2, 59.0, 55.7, 55.3, 31.3, 31.2, 28.6, 28.5, 28.4, 28.3, 22.5, 22.5, 18.8, 18.6, 15.6, 15.5, 13.9, 13.9. HRMS (EI) m/z calculated for $[M+Na]^+$ 232.1308, found 232.1305.

*4.2.5. (7E)-7-Hexylidene-4-propyl-3-oxa-1-azabicyclo[4.1.0] heptan-2-one (**9a**).* The product was obtained as an inseparable mixture of diastereomers (dr=2.5:1) in 34% yield as a thick, colorless oil using general procedure B. ^{1}H NMR (500 MHz, C_6D_6) δ 5.57 (t, J=7.0 Hz, 0.83H), 5.18 (t, J=7.5 Hz, 0.34H), 3.84 (m, 1.32H), 2.66 (m, 1.98H), 1.94 (q, J=7.3 Hz, 2.00H), 1.47 (m, 0.83H), 1.02–1.37 (m, 13.64H), 0.91 (m, 5.71H), 0.72 (m, 5.57H). ^{13}C NMR (125 MHz, C_6D_6) δ 158.1, 157.7, 129.6, 129.1, 104.9, 104.0, 82.3, 81.9, 40.9, 40.8, 39.3, 39.3, 34.0, 33.9, 32.4, 31.9, 31.9, 31.4, 30.8, 29.9, 25.2, 25.1, 20.3, 16.6, 16.5, 16.1. HRMS (ESI) m/z calculated for $[M+H]^+$ 238.1802, found 238.1797.

*4.2.6. 4-(Octa-1,2-dien-1-yl)-5-propyl-1,3-oxazolidin-2-one (**9b**).* The product was obtained as a 2.2:1 inseparable mixture of diastereomers in 30% yield as a thick, colorless oil using general procedure B. ^{1}H NMR (500 MHz, C_6D_6) δ 6.96 (br s, 1H), 5.20 (m, 1H), 4.78–4.93 (m, 1H), 3.96–4.09 (m, 1H), 3.49–3.74 (m, 1H), 1.90 (m, 2H), 1.10–1.50 (m, 10H), 0.88 (overlapping t, J=7.1 Hz, 3H), 0.67 (overlapping t, J=7.3 Hz, 3H). ^{13}C NMR (125 MHz, C_6D_6) δ 204.2, 203.9, 203.8, 159.4, 94.7, 94.5, 94.3, 94.2, 91.5, 91.5, 88.7, 88.6, 82.1, 80.3, 79.5, 57.7, 57.5, 55.5, 36.0, 35.9, 32.5, 32.4, 31.3, 31.3, 31.2, 28.7, 28.6, 28.6, 28.4, 28.4, 28.3, 22.5, 22.5, 19.0, 18.1, 17.4, 13.9, 13.9, 13.5, 13.5, 13.0. HRMS (ES) m/z calculated for $[M+H]^+$ 238.1802, found 238.1800.

*4.2.7. (7E)-7-Hexylidene-5-methyl-3-oxa-1-azabicyclo[4.1.0]heptan-2-one (**10a**).* The product was obtained as an oil in 21% yield as

a separable 3:1 mixture of *E*/*Z* diastereomers using general procedure B. The dr was greater than 95:5 for both the *E* and *Z* isomers. Major diastereomer (*E*): ^{1}H NMR (500 MHz, C_6D_6) δ 5.55 (t, *J*=6.8 Hz, 1H), 3.48 (t, *J*=10.8 Hz, 1H), 3.38 (dd, *J*=10.4, 3.8 Hz, 1H), 2.40 (d, *J*=8.1 Hz, 1H), 1.90 (app q, *J*=7.1 Hz, 2H), 1.07–1.24 (m, 7H), 0.85 (t, *J*=7.2 Hz, 3H), 0.37 (d, *J*=6.9 Hz, 3H). ^{13}C NMR (125 MHz, C_6D_6) δ 155.4, 126.2, 101.9, 73.7, 44.4, 31.6, 30.5, 28.9, 28.5, 22.8, 14.1, 13.1. HRMS (ESI) *m*/*z* calculated for $[M]^+$ 209.1411, found 209.1402. Minor diastereomers (*Z*): ^{1}H NMR (500 MHz, C_6D_6) δ 5.55 (t, *J*=7.2 Hz, 1H), 3.76 (dd, *J*=10.6, 2.5 Hz, 1H), 3.34 (dd, *J*=10.8, 3.0 Hz, 1H), 2.85 (d, *J*=6.6 Hz, 1H), 1.85 (m, 2H), 1.44 (m, 1H), 1.16 (m, 1H), 0.85 (t, *J*=7.1 Hz, 3H), 0.48 (d, *J*=7.4 Hz, 3H). ^{13}C NMR (125 MHz, C_6D_6) δ 155.2, 123.6, 103.7, 72.4, 43.7, 31.6, 29.4, 28.8, 25.3, 22.7, 14.1, 12.6. HRMS (ESI) *m*/*z* calculated for $[M]^+$ 209.1411, found 209.1417.

*4.2.8. 4-Methyl-4-(octa-1,2-dien-1-yl)-1,3-oxazolidin-2-one (**10b**).* The product was obtained as an oil in 57% yield. ^{1}H NMR (500 MHz, C_6D_6) δ 7.35 (br s, 1H), 7.28 (br s, 1H), 5.19 (m, 1H), 5.03 (m, 1H), 3.88 (m, 1H), 3.55 (br d, *J*=8.8 Hz, 1H), 1.88 (m, 2H), 1.25 (overlapping signals, 6H), 1.06 (br s, 3H), 0.90 (m, 3H). ^{13}C NMR (125 MHz, C_6D_6) δ 201.8, 159.4, 96.7, 96.6, 95.9, 95.7, 75.4, 56.6, 31.3, 28.6, 28.5, 25.3, 25.2, 22.5, 13.9. HRMS (EI) *m*/*z* calculated for $[M+H]^+$ 210.1489, found 210.1495.

*4.2.9. (7E)-7-Hexylidene-4,4-dimethyl-3-oxa-1-azabicyclo- [4.1.0]heptan-2-one (**11a**).* The product was obtained as an oil in 10% (condition B) yield as a 2.8:1 mixture of *E*/*Z* isomers. Condition D gave a 5% yield of the product as a 1.9:1 mixture of *E*/*Z* isomers. ^{1}H NMR (500 MHz, C_6D_6) δ 5.57 (t, *J*=6.3 Hz, 1H major), 5.17 (t, *J*=7.7 Hz, 1H minor), 2.67 (overlapping signals, 2H total), 1.95 (br dd, *J*=14.0, 7.2 Hz, 2H), 1.17 (overlapping signals, 16H total), 0.89 (overlapping signals, 9H). ^{13}C NMR (125 MHz, C_6D_6) δ 183.6, 155.3, 102.3, 101.4, 83.3, 36.9, 34.0, 31.3, 29.7, 28.7, 28.7, 28.1, 27.2, 26.7, 24.3, 22.5, 22.5, 13.9, 13.9. HRMS (EI) *m*/*z* calculated for $[M]^+$ 223.1567, found 223.1563.

*4.2.10. 5,5-Dimethyl-4-(octa-1,2-dien-1-yl)-1,3-oxazolidin-2-one (**11b**).* The product was obtained as a colorless oil that solidified to a waxy solid upon refrigeration in 72% yield using general procedure B and 84% yield using general procedure D. ^{1}H NMR (500 MHz, C_6D_6) δ 7.02 (br s, 1H), 5.12 (m, 1H), 4.74 (m, 1H), 3.50 (m, 1H), 1.84 (m, 2H), 1.22 (m, 6H), 1.01 (four singlets, 6H), 0.84 (two triplets, *J*=7.2, 6.8 Hz, 3H). ^{13}C NMR (125 MHz, C_6D_6) δ 204.6, 204.4, 159.2, 94.7, 94.2, 89.4, 89.3, 83.0, 82.9, 82.9, 61.9, 61.6, 31.6, 31.5, 28.9, 28.9, 28.7, 28.6, 27.1, 22.9, 22.8, 14.2, 14.2. HRMS (ESI) *m*/*z* calculated for $[M]^+$ 223.1567, found 223.1561.

4.2.11. (7E)-7-Hexylidene-4,5-dimethyl-3-oxa-1azabicyclo [4.1.0]. Heptan-2-one (**12a**). The product was obtained in 12% yield using general procedure C as a mixture of four stereoisomers. ^{1}H NMR (500 MHz, C_6D_6) δ 5.58 (2 overlapping t, *J*=7.2, 6.7 Hz, 0.48H), 6.7 (t, *J*=7.4 Hz, 0.14H), 5.07 (t, *J*=7.4 Hz, 0.20H), 3.98 (m, 0.45H), 3.67 (m, 0.41H), 2.88 (d, *J*=6.7 Hz, 0.21H), 2.81 (d, *J*=6.7 Hz, 0.20H), 2.65 (m, 0.63H), 2.36 (m, 0.42H), 1.89 (m, 1.53H), 1.46 (m, 0.60H), 1.10–1.40 (m, 6.95H), 0.95 (m, 0.42H), 0.86 (m, 3.72H), 0.77 (m, 3.13H), 0.35–0.44 (m, 3.00H). ^{13}C NMR (125 MHz, C_6D_6) δ 155.1, 126.4, 124.0, 123.7, 103.9, 102.9, 101.2, 80.7, 80.4, 77.5, 77.2, 44.1 (2), 43.9, 36.4, 31.4, 31.3 (2), 29.8, 29.4, 29.1, 28.7, 28.5, 28.3, 27.4, 22.5 (2), 17.7, 17.3, 14.0, 13.9, 12.9, 7.5, 7.3. HRMS (ESI) *m*/*z* calculated for $[M]^+$ 223.1567, found 223.1576.

*4.2.12. 4,5-Dimethyl-4-(octa-1,2-dien-1-yl)-1,3-oxazolidin-2-one (**12b**).* The product was obtained in 61% yield using general procedure C as a 1.3:1 mixture of diastereomers at the two Me-bearing carbons. ^{1}H NMR (500 MHz, C_6D_6) δ 6.66 (br s, 1H), 5.10–5.30 (m, 1H), 4.80–4.97 (m, 1H), 4.11 (m, 0.5H), 3.82–3.93 (m, 0.5H), 1.87 (m, 2H), 1.14–1.43 (m, 6H), 0.84–0.98 (overlapping signals, 9H). ^{13}C NMR (125 MHz, C_6D_6) δ 202.7, 202.6, 202.6, 158.7, 96.6, 96.5, 95.6, 95.5, 95.3, 95.2, 93.6, 81.8, 80.5, 59.6, 59.3, 31.4, 31.3, 31.3, 28.6, 28.6, 28.5, 24.5, 22.5, 22.4, 20.2, 20.1, 15.1, 15.0, 13.9, 13.9, 13.7, 13.5. HRMS (ESI) *m*/*z* calculated for $[M+H]^+$ 224.1646, found 224.1651.

*4.2.13. (8E)-8-Hexylidene-3-oxa-2-thia-1-azabicyclo[5.1.0]octane 2,2-dioxide (**13a**).* The product was obtained in 38% yield as a thick, colorless oil using general procedure B. ^{1}H NMR (500 MHz, C_6D_6) δ 5.57 (t, *J*=6.8 Hz, 1H), 3.70 (td, *J*=11.6, 1.7 Hz, 1H), 3.51 (dt, *J*=12.1, 3.5 Hz, 1H), 2.96 (s, 1H), 1.92 (m, 1H), 1.82 (2dd, *J*=7.3, 7.3 Hz, 2H total), 1.68 (m, 1H), 1.04–1.36 (m, 7H), 0.88 (overlapping m and t, *J*=7.0 Hz, 4H). ^{13}C NMR (125 MHz, C_6D_6) δ 128.2, 128.0, 127.8, 122.2, 106.8, 70.7, 45.9, 31.6, 28.8, 28.6, 27.2, 26.6, 22.7, 14.1. HRMS (ESI) *m*/*z* calculated for $[M+Na]^+$ 268.0978, found 268.0972.

*4.2.14. 4-(Octa-1,2-dien-1-yl)-1,2,3-oxathiazinane 2,2-dioxide (**13b**).* The product was obtained using general procedure B in 42% yield as a thick, colorless oil that solidified to a white wax upon refrigeration. ^{1}H NMR (500 MHz, C_6D_6) δ 5.12 (m, 1H), 4.80 (br s, 1H), 4.19 (dd, *J*=11.8, 11.8 Hz, 1H), 3.91 (m, 2H), 3.69 (m, 1H), 1.83 (m, 2H), 1.07–1.33 (m, 7H), 0.89 (2 sets of triplets, *J*=7.0 Hz, 3H), 0.78 (m, 1H). ^{13}C NMR (125 MHz, C_6D_6) δ 203.2, 202.8, 96.2, 95.9, 91.4, 91.3, 71.1, 71.0, 53.7, 31.6, 31.5, 29.6, 29.1, 29.0, 28.9, 28.7, 28.6, 22.7, 14.2. HRMS (EI) *m*/*z* calculated for $[M+H]^+$ 246.1159, found 246.1157.

*4.2.15. 4-(Octa-1,2-dien-1-yl)-1,3-oxazinan-2-one (**14b**).* The product was obtained as two diastereomers using general procedure C in 33% yield. ^{1}H NMR (300 MHz, C_6D_6) δ 7.1 (br s, 1H), 5.19 (m, 1H), 4.88 (m, 1H), 3.73 (m, 1H), 3.58–3.43 (overlapping m, 2H), 2.04–1.85 (m, 2H), 1.45–1.03 (overlapping signals, 8H total), 0.81 (2t, 3H, *J*=6.8 Hz). ^{13}C NMR (125 MHz, C_6D_6) δ 203.2, 203.1, 154.0, 153.9, 95.6, 95.3, 93.3, 64.4, 49.5, 49.3, 31.6, 29.0, 28.9, 28.8, 27.5, 27.4, 22.8, 14.2.

*4.2.16. 5-Methyl-4-(octa-1,2-dien-1-yl)-1,3-oxazinan-2-one (**15b**).* The product was obtained in 70% yield in a dr of 2:1 between the amine and the ring methyl group. Major diastereomer (only one allene stereoisomer observable by NMR): ^{1}H NMR (500 MHz, C_6D_6) δ 6.71 (br s, 1H), 5.06 (m, 1H), 4.90 (m, 1H), 3.70 (m, 1H), 3.41 (dd, *J*=8.1, 2.5 Hz, 1H), 1.92 (app q, *J*=6.4 Hz, 2H), 1.82 (m, 2H), 1.19–1.38 (m, 6H), 0.89 (t, *J*=7.1 Hz, 3H), 0.80 (d, *J*=5.8 Hz, 3H). ^{13}C NMR (125 MHz, C_6D_6) δ 205.9, 205.9, 159.1, 159.0, 90.7, 84.5, 73.9, 56.8, 39.8, 31.1, 28.7, 28.5, 28.4, 24.6, 22.3, 13.7. HRMS (EI) *m*/*z* calculated for $[M+Na]^+$ 246.1465, found 246.1468. Minor diastereomer (observable as a 1:1 mixture of allene stereoisomers by NMR): ^{1}H NMR (500 MHz, C_6D_6) δ 7.34 (2 br s, 1H), 5.21 (m, 1H), 4.90 (m, 1H), 3.72 (m, 1H), 3.34 (m, 1H), 3.18 (m, 1H), 2.00 (qd, *J*=7.3, 2.8 Hz, 1H), 1.90 (qt, *J*=7.1, 2.5 Hz, 1H), 1.15–1.43 (m, 7H), 0.92 (t, *J*=7.4 Hz, 1.5H), 0.88 (t, *J*=7.4 Hz, 3H), 0.50 (dd, *J*=6.4, 3.0 Hz, 1.5H). ^{13}C NMR (125 MHz, C_6D_6) δ 204.3, 204.2, 154.1, 94.2, 93.8, 92.1, 92.0, 69.9, 69.9, 57.1, 56.6, 31.8, 31.6, 31.3, 31.3, 28.8, 28.8, 28.7, 28.6, 22.5, 22.5, 14.0, 13.9, 12.7. HRMS (EI) *m*/*z* calculated for $[M+Na]^+$ 246.1465, found 246.1461.

*4.2.17. (7E)-7-Hexylidene-6-methyl-3-oxa-1-azabicyclo[4.1.0]heptan-2-one (**16a**).* The product was obtained in 18% yield. ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.46 (t, *J*=6.8 Hz, 1H), 3.76 (ddd, *J*=10.8, 4.1, 1.0 Hz, 1H), 3.53 (ddd, *J*=10.8, 3.2, 3.2 Hz, 1H), 1.87 (app q, *J*=7.1 Hz, 2H), 1.05–1.28 (m, 8H), 1.03 (s, 3H), 0.86 (t, *J*=7.4 Hz, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 156.2, 132.5, 128.3, 128.0, 127.7, 101.4, 66.9, 45.3, 31.5, 29.3, 29.0, 28.4, 22.7, 21.6, 14.1.

*4.2.18. 4-(Nona-2,3-dien-2-yl)-1,3-oxazolidin-2-one (**16b**).* The product was obtained in 28% yield as a 1:1 mixture of stereoisomers. ^{1}H NMR (500 MHz, C_6D_6) δ 6.84 (2 br s, 1H total), 5.12 (m, 1H), 3.74 (m,

2H), 3.56 (m, 1H), 1.87 (app q, *J*=7.3, 2H), 1.42 (2d, *J*=2.5 and 3.3 Hz, 3H total), 1.18–1.34 (m, 6H), 0.89 (2t, *J*=7.3, 6.9 Hz, 3H). ^{13}C NMR (125 MHz, C_6D_6) δ 200.4, 159.8, 98.9, 98.8, 94.2, 94.0, 68.4, 68.3, 54.6, 54.5, 31.3, 28.7, 28.6 (2), 22.5, 14.4, 14.3, 13.9.

4.3. General procedure for the cyclocarbonylation of allenic amines

General procedure for the cyclocarbonylation of allenic carbamates: A 22 mL stainless steel Parr reactor was charged with the allenic carbamate (1.07 mmol, 1.0 equiv) in 3 mL dry dioxane. The solution was sparged with a flow of dry N_2 for 10 min prior to addition of $Ru_3(CO)_{12}$ (0.021 mmol, 0.02 equiv) and triethylamine (1.28 mmol, 1.2 equiv). The system was sealed and flushed three times with 300 psi of CO. Finally, the reactor was pressurized to 400–500 psi of CO and stirred at 80 °C for 8–12 h. The reaction was cooled and the remaining CO pressure carefully released, the contents transferred to a flask using ether. The volatiles were removed under reduced pressure and the residue was chromatographed on silica gel (1:1 hexane/EtOAc) to give the desired α,β-unsaturated γ-lactam product. Increasing the reaction temperature to 100 °C led to complete decarboxylation.

*4.3.1. 6-Hexyl-4,4a-dihydropyrrolo[1,2-c][1,2,3]oxathiazin-7(3H)-one 1,1-dioxide (**17a**).* The product was obtained in 24% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.86 (m, 1H), 4.86 (m, 1H), 4.67 (m, 2H), 2.27 (m, 3H), 1.75 (m, 1H), 1.54 (app p, *J*=7.1 Hz, 2H), 1.32 (m, 6H), 0.89 (t, *J*=7.0 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.9, 139.8, 72.3, 60.0, 31.4, 29.9, 28.8, 27.1, 25.4, 22.5, 14.0. HRMS (ESI) *m*/*z* calculated for $[M+H]^+$ 274.1108, found 274.1118.

*4.3.2. 6-Hexyl-7a-methyl-1H-pyrrolo[1,2-c][1,3]oxazole-3,5(7aH)-dione (**18a**).* The product was obtained in 78% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.85 (t, *J*=1.5 Hz, 1H), 4.28 (d, *J*=8.4 Hz, 1H), 4.16 (d, *J*=8.4 Hz, 1H), 2.28 (tt, *J*=7.9, 1.5 Hz, 2H), 1.63 (s, 3H), 1.53 (m, 2H), 1.32 (m, 6H), 0.89 (t, *J*=6.7 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.6, 150.4, 145.5, 140.9, 74.4, 66.2, 31.4, 28.7, 27.1, 25.3, 24.2, 22.4, 14.0. HRMS (ESI) *m*/*z* calculated for $[M+Na]^+$ 260.1258, found 260.1264.

*4.3.3. 6-Hexyl-1H-pyrrolo[1,2-c][1,3]oxazole-3,5(7aH)-dione (**19a**).* The product was obtained in 57% yield. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.95 (dt, *J*=1.7, 1.6 Hz, 1H), 5.13 (m, 1H), 4.70 (app t, *J*=8.4 Hz, 1H), 4.08 (dd, *J* 10.2, 8.4 Hz, 1H), 2.30 (td, *J*=7.1, 1.6 Hz, 2H), 1.55 (m, 2H), 1.20–1.39 (m, 6H), 0.89 (t, *J* 7.0 Hz, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.0, 149.6, 141.9, 139.4, 68.3, 58.9, 30.4, 27.8, 26.2, 24.6, 21.5, 13.0.

*4.3.4. 3-Hexyl-5-methylidene-1,5-dihydro-2H-pyrrol-2-one (**19b**).* The product was obtained in a yield of 27%. Major diastereomer: ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.80 (br s, 1H), 6.63 (s, 1H), 4.92 (s, 1H), 4.75 (s, 1H), 2.34 (t, *J*=7.7 Hz, 2H), 1.57 (m, 2H), 1.2–1.42 (m, 6H), 0.89 (t, *J*=6.9 Hz, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 173.0, 142.8, 140.3, 131.1, 96.2, 31.6, 29.0, 27.6, 25.1, 22.5, 14.0.

*4.3.5. 6-Hexyl-1,1-dimethyl-1H-pyrrolo{1,2-c}{1,3}oxazole-3,5(7aH)-dione (**20a**).* The product was obtained in 60% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.75 (s, 1H), 4.69 (s, 1H), 2.32 (t, *J*=7.5 Hz, 2H), 1.65 (s, 3H), 1.49–1.58 (m, 2H), 1.25–1.37 (m, 6H), 1.15 (s, 3H), 0.88 (t, *J*=6.6 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 168.7, 149.4, 143.5, 137.7, 84.5, 68.4, 31.4, 28.8, 27.3, 26.0, 25.6, 23.0, 22.5, 14.0. HRMS (ESI) *m*/*z* calculated for $[M+Na]^+$ 274.1414, found 274.1410.

*4.3.6. 3-Hexyl-5-(propan-2-ylidene)-1,5-dihydro-2H-pyrrol-2-one (**20b**).* The material was obtained as a minor product in 12% yield when the reaction was run at 80 °C, but could be increased to 88% when the reaction was run at 100 °C and 500 psi of CO. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (br s, 1H), 6.88 (s, 1H), 2.34 (t, *J*=7.5 Hz, 2H), 1.94 (s, 3H), 1.90 (s, 3H), 1.57 (m, 2H), 1.28–1.38 (m, 6H), 0.89 (t, *J*=6.9 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.5, 137.2, 133.1, 127.5, 119.4, 31.6, 29.0, 28.0, 25.3, 22.6, 19.7, 19.7, 14.1. HRMS (ESI) *m*/*z* calculated for $[M]^+$ 207.1618, found 207.1625.

*4.3.7. 6-Hexyl-1-methyl-1H-pyrrolo[1,2-c][1,3]oxazole-3,5(7aH)-dione (**21a**).* The desired product was obtained in a yield of 53%. ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.85 (d, *J*=0.7 Hz, 1H), 4.58 (dd, *J*=9.4, 0.7 Hz, 1H), 4.39 (app dq, *J*=9.5, 6.2 Hz, 1H), 2.2 (t, *J*=7.8 Hz, 2H), 1.61 (d, *J*=6.2 Hz, 3H), 1.54 (m, 2H), 1.25–1.40 (m, 6H), 0.89 (t, *J*=6.7 Hz, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.7, 150.3, 143.7, 139.0, 79.3, 66.9, 31.7, 29.0, 27.4, 25.9, 22.7, 18.5, 14.2.

*4.3.8. (5Z)-5-Ethylidene-3-hexyl-1,5-dihydro-2H-pyrrol-2-one and (5E)-5-ethylidene-3-hexyl-1,5-dihydro-2H-pyrrol-2-one (**21b**).* The product was obtained as a 2:1 mixture of *E*/*Z* isomers in 25% yield when the reaction was run at 80 °C. Increasing the reaction temperature to 100 °C increased the yield to 91% as a 10:1 mixture of *E*/*Z* isomers. Major isomer (*E*): ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.18 (br s, 1H), 6.91 (s, 1H), 5.43 (q, *J*=7.7 Hz, 1H), 2.35 (t, *J*=7.6 Hz, 2H), 1.91 (d, *J*=7.6 Hz, 3H), 1.57 (m, 2H), 1.26–1.39 (m, 6H), 0.89 (t, *J*=6.7 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.0, 139.2, 137.5, 126.2, 109.1, 31.6, 29.0, 27.8, 25.4, 22.6, 14.1, 12.9. HRMS (ESI) *m*/*z* calculated for $[M]^+$ 193.1462, found 193.1461. Minor isomer (*Z*): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.70 (br s, 1H), 6.57 (s, 1H), 5.16 (q, *J*=7.6 Hz, 1H), 2.32 (t, *J*=7.7 Hz, 2H), 1.86 (d, *J*=7.6 Hz, 3H), 1.56 (m, 2H), 1.25–1.38 (m, 6H), 0.88 (t, *J*=6.7 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.5, 137.9, 137.7, 131.6, 108.7, 31.6, 29.0, 27.8, 25.1, 22.6, 14.1, 13.0. HRMS (ESI) *m*/*z* calculated for $[M]^+$ 193.1462, found 193.1453.

*4.3.9. cis- and trans-6-Hexyl-1,7a-dimethyl-1H-pyrrolo[1,2-c][1,3]oxazole-3,5(7aH)-dione (**22a**).* The product was obtained in 97% yield as a 1.3:1 mixture of diastereomers. The dr was maintained from the allene carbamate substrate through both the C–H amination and the cyclocarbonylation step. The two resulting diastereomers could be separated by column chromatography. Major diastereomer: ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.77 (t, *J*=1.5 Hz, 1H), 4.44 (app q, *J*=6.6 Hz, 1H), 2.28 (td, *J*=7.8, 1.5 Hz, 2H), 1.53 (m, 2H), 1.44–1.49 (overlapping s and d, 6H), 1.24–1.38 (m, 6H), 0.89 (t, *J*=6.9 Hz, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.2, 149.7, 144.8, 141.4, 81.3, 68.8, 31.4, 28.8, 27.1, 25.4, 22.5, 18.5, 14.0 (2). Minor diastereomer: ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.70 (t, *J*=1.5 Hz, 1H), 4.53 (app q, *J*=6.6 Hz, 1H), 2.30 (td, *J*=7.3, 1.4 Hz, 2H), 1.24–1.62 (overlapping signals, 11H), 1.14 (d, *J*=6.4 Hz, 3H), 0.88 (t, *J*=6.8 Hz, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.0, 149.6, 143.9, 141.1, 81.3, 68.7, 31.4, 28.7, 27.3, 25.3, 24.7, 22.5, 18.0, 14.0.

*4.3.10. 6-Hexyl-7-methyl-1H-pyrrolo[1,2-c][1,3]oxazole-3,5(7aH)-dione (**23a**).* The product was obtained in 45% yield. ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.94 (app t, *J*=9.3 Hz, 1H), 4.05 (dd, *J*=9.9, 8.5 Hz, 1H), 2.25 (t, *J*=7.8 Hz, 2H), 2.02 (s, 3H), 1.46 (m, 2H), 1.28 (m, 6H), 0.88 (t, *J*=7.0 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 169.6, 153.6, 150.9, 135.1, 68.6, 62.3, 31.5, 29.1, 27.9, 23.5, 22.5, 14.0, 13.0.

*4.3.11. (5E)-3-Hexyl-5-propylidene-1,5-dihydro-2H-pyrrol-2-one (**24b**).* The product was obtained in 70% yield as only the *E* isomer. ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.39 (br s, 1H), 6.89 (s, 1H), 5.42 (t, *J*=8.3 Hz, 1H), 2.35 (t, *J*=7.7 Hz, 2H), 2.26 (q, *J*=7.4 Hz, 2H), 1.59 (m, 2H), 1.48 (m, 2H), 1.28–1.39 (m, 6H), 0.94 (t, *J*=7.2 Hz, 3H), 0.89 (t, *J*=6.7 Hz, 3H). ^{13}C NMR (125 MHz, $CDCl_3$) δ 172.2, 139.3, 137.1, 126.5, 114.8, 31.6, 29.5, 29.0, 27.8, 25.4, 23.3, 22.6, 14.1, 13.6. HRMS (ESI) *m*/*z* calculated for $[M]^+$ 221.1775, found 221.1788.

Acknowledgements

The authors thank the University of Wisconsin, Madison for support of this research and John Hershberger and Dagmara

Marston for insightful comments. Nathan Connell and Alan Meis are thanked for assistance in the preparation of substrates. The NMR and Mass Spectrometry facilities are funded by the NSF (CHE-9974839, CHE-9304546, CHE-9208463, CHE-9629688) and the University of Wisconsin, as well as the NIH (RR08389-01).

Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.tet.2011.03.026.

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